X-Ray Binary Systems in the Small Magellanic Cloud

P. Kahabka[1,2]**, W. Pietsch**[3]

[1] Astronomical Institute, University of Amsterdam, Kruislaan 403, NL–1098 SJ Amsterdam, The Netherlands
[2] Center for High Energy Astrophysics, University of Amsterdam, Kruislaan 403, NL–1098 SJ Amsterdam, The Netherlands
[3] Max-Planck-Institut für extraterrestrische Physik, D–85740 Garching bei München, Federal Republic of Germany

Abstract. We present the result of a systematic search for spectrally hard and soft X-ray binary systems in the Small Magellanic Cloud (SMC). This search has been applied to *ROSAT PSPC* data (0.1-2.4 keV) collected during nine pointed observations towards this galaxy covering a time span of ~ 2 years from October 91 till October 93. Strict selection criteria have been defined in order to confine the sample of candidates. Finally seven spectrally hard and four spectrally soft sources were selected from the list as candidates for binaries in the SMC. The sample is luminosity limited (above $\sim 3 \times 10^{35}$ erg s^{-1}). SMC X-1 has been observed during a full binary orbit starting with a low-state covering an X-ray eclipse and emerging into a bright long-duration flare with two short-duration flares separated by ~ 10 hours. The Be type transient SMC X-2 has been redetected by *ROSAT* (second reported outburst). Variability has been found in the X-ray source RX J0051.8-7231 already discovered with *Einstein* and in RX J0052.1-7319 which is also known from *Einstein* observations. RX J0101.0-7206 has been discovered at the north-eastern boundary of the giant SMC HII region N66 during an X-ray outburst and half a year later during a quiescent phase. A variable source, RX J0049.1-7250, located north-east of the SMC supernova remnant N 19 and which may either be an X-ray binary or an AGN turns out to be strongly absorbed. It may be located behind the SMC. If it is an X-ray binary then it radiates at the Eddington limit in the X-ray bright state. Another variable and hard X-ray source RX J0032.9-7348 has been discovered at the south-eastern border of the body of the SMC. A high mass X-ray binary nature is favored for this source.

A high mass X-ray binary nature is favored for the persistent sources where an optical counterpart of spectral type O or B has been identified. A possible Be type nature is favored for the few transient X-ray sources for which an optical identification with a B star has been achieved. We find about equal numbers of persistent (and highly vari-
able) and transient X-ray binaries and binary candidates. Sources for which no optical candidate has been found in catalogs are candidate low-mass X-ray binaries (LMXBs) or black hole binaries. We searched for CAL 87 like systems in the SMC pointed catalog and found none. This implies that these systems are very rare and currently not existent in the SMC. A new candidate supersoft source RX J0103.8-7254 has been detected. We cannot exclude that it is a foreground object.

Key words: binaries: close – Magellanic Clouds – X-rays: stars – Stars: individual: SMC X-1, SMC X-2, RX J0051.8-7231, RX J0052.1-7319, RX J0101.0-7206, RX J0049.1-7250, RX J0032.9-7348

1. Introduction

The study of X-ray binary populations in galaxies outside of our own Galaxy is of major interest. First the evolution of our Galaxy is specific which reflects itself in their different stellar populations, their ages and distributions. The Magellanic Clouds (MCs), satellites of our own Galaxy, show different chemical compositions are irregular in shape and are heavily interacting with our Galaxy (Gardiner et al. 1994). This influences the star formation history. Any kind of study of stellar populations is therefore of particular interest. X-ray binaries are interacting binaries with mass transfer from a donor star to a compact object, a white dwarf, neutron star or a black hole. They are evolved objects with the compact object being the product of evolution of a more massive star (cf. van den Heuvel 1994, Livio 1994). The neutron star (NS) binaries are classified into high- and low-mass X-ray binaries (HMXBs and LMXBs). The HMXBs have donor stars more massive than $\sim$8-10 M$_\odot$ and belong to the youngest stellar population of the Galaxy (age $\lesssim 10^7$ yr). The LMXBs belong to a much older stellar population (age $5 - 15 \times 10^9$ yr).

arXiv:astro-ph/9706075v1 9 Jun 1997

They are concentrated in the Galactic bulge and in the globular clusters (van den Heuvel 1992).

The Magellanic System (MS) can be described as a binary system consisting of the LMC and the SMC which are orbiting around the Galaxy (cf. Gardiner et al. 1994). In this description the MS forms a great circle in the sky perpendicular to the Galactic poles. The MCs are presently near the perigalacticon and were never closer to the Galaxy. Due to the frictional force in the Galactic halo the orbital period of the MCs about the Galaxy is decaying (last orbital period $\sim$1.3 Gyr, initial orbital period $\sim$3 Gyr). The present centre-to-centre distance between the MCs is $\sim$21 kpc. A close encounter between the MCs occurred $\sim$0.2-0.4 Gyr ago at a distance of 7 kpc. The previous encounter was at a much larger distance of 13 kpc. This may have stimulated star formation in the MCs ($\sim$0.2 Gyr ago) and may explain why the star formation histories in the MCs are so different from those in the Galaxy. There is evidence of recent externally stimulated star formation in the *Wing* of the SMC. The age of the stellar associations in the SMC *Wing* and in the inter-Cloud region is less than 0.05 Gyr. This would require a delay of at least 80 million years between the last LMC-SMC encounter and the onset of star formation activity. The spatial structure of the SMC has e.g. been deduced from observations of Cepheids. According to this view the SMC is composed of a 5-to-1 bar (seen edge-on), a near arm in the north-east, and a far arm in the south-west. There is in addition material pulled out of the centre of the SMC (by the LMC) which is seen in projection in front of the arm in the south-west (cf. Caldwell & Coulson 1986). A point to note is that the SMC spiral arms are very young. It is not expected that the old population of LMXBs have yet formed there. Actually before *ROSAT* no single candidate LMXB has been known in the SMC. In the SMC bulge LMXBs may well have formed due to its considerable age of $\sim$15 Gyr. But possible kicks and small number statistics make it difficult to test these scenarii.

Before the observations of the SMC with *ROSAT* six hard X-ray binary sources have been reported in the SMC (Clark et al. 1978, Seward & Mitchell 1981, Inoue et al. 1983, Bruhweiler et al. 1987, Wang & Wu 1992, Whitlock & Lochner 1994). The first SMC X-ray sources discovered with rockets, *Uhuru*, *SAS-3* and HEAO-1 have been found to be superluminous with X-ray luminosities in excess of 10^{38}erg sec^{-1} and in part of transient nature (SMC X-1, SMC X-2, SMC X-3 and H0107-750). The other two sources RX J0051.8-7231 and RX J0052.1-7319 have been first reported from *Einstein* observations. The *ROSAT* sources are not yet firmly identified with OB stars.

ROSAT performed several pointings to the field of the SMC (body and wing). A point source catalog of 250 (preliminary and unscreened) X-ray sources has been compiled from 9 pointed observations carried out by the authors of this paper. The total list of sources detected in these fields will be presented in a separate paper. The X-ray

sources have been classified into five categories. The new and distinct class of supersoft sources has been presented in Kahabka, Pietsch & Hasinger (1994). The new sample of supernova remnants detected in the SMC will be published in Kahabka et al. (1996). The bulk of sources, background AGNs and foreground stars, will be discussed together with the total source list.

We report in this paper about the hard and soft X-ray binary population studied with *ROSAT* in the SMC. In section 2 we describe the *ROSAT* observations, the data analysis and the selection criteria for hard and soft sources. In section 3 we report about the observational results of the individual systems, the temporal and the spectral properties achieved during the pointed observations and results for SMC X-1 during the all-sky survey observation. Then we detail results on the individual systems considering information deduced in previous work. In section 4 we investigate source variability and transient behavior, the luminosity distribution, extrapolate from the discussed SMC populations to the Galactic populations and discuss the nature of the rejected candidate X-ray binaries. Finally we summarize in section 5 our results.

2. Observations and data analysis

The observations reported in this paper were carried out with the *PSPC* detector onboard the *ROSAT* observatory during the all-sky survey (RASS) and during 9 pointed observations in the time from 8 October 1991 to 14 October 1993. The satellite, it's X-ray telescope (XRT) and the focal plane detector (*PSPC*) used have been discussed in detail by Trümper et al. (1983) and Pfeffermann et al. (1986).

2.1. All-sky survey observations

The field of the SMC covered by the pointed observations has been observed in the *RASS* survey between 21 October 1990 and 31 October 1990. In the direction to the SMC the survey is complete to an apparent luminosity (not corrected for interstellar absorption) of $\sim 3 \times 10^{35}$erg s^{-1} (Kahabka & Pietsch 1993). The corresponding intrinsic luminosity is $\sim 8 \times 10^{35}$ erg s^{-1}, as found from applying the constraints (conversion factor) from section 2.4 used for the pointed data.

2.2. ROSAT pointed observations

The pointed observations reported in this paper will be designated as regions A, B, C, D, E, F, G, X and Y. Table 1 gives a log of the field centers, observation intervals and exposure times. Regions A and B have originally been observed with a reduced time (observations A1 and B1) and about half a year later the observations were completed (observations A2 and B2). A merged (0.1-2.4 keV) X-ray image of these fields only using the inner 45' of the detector is shown in Figure 1. The coverage due to the
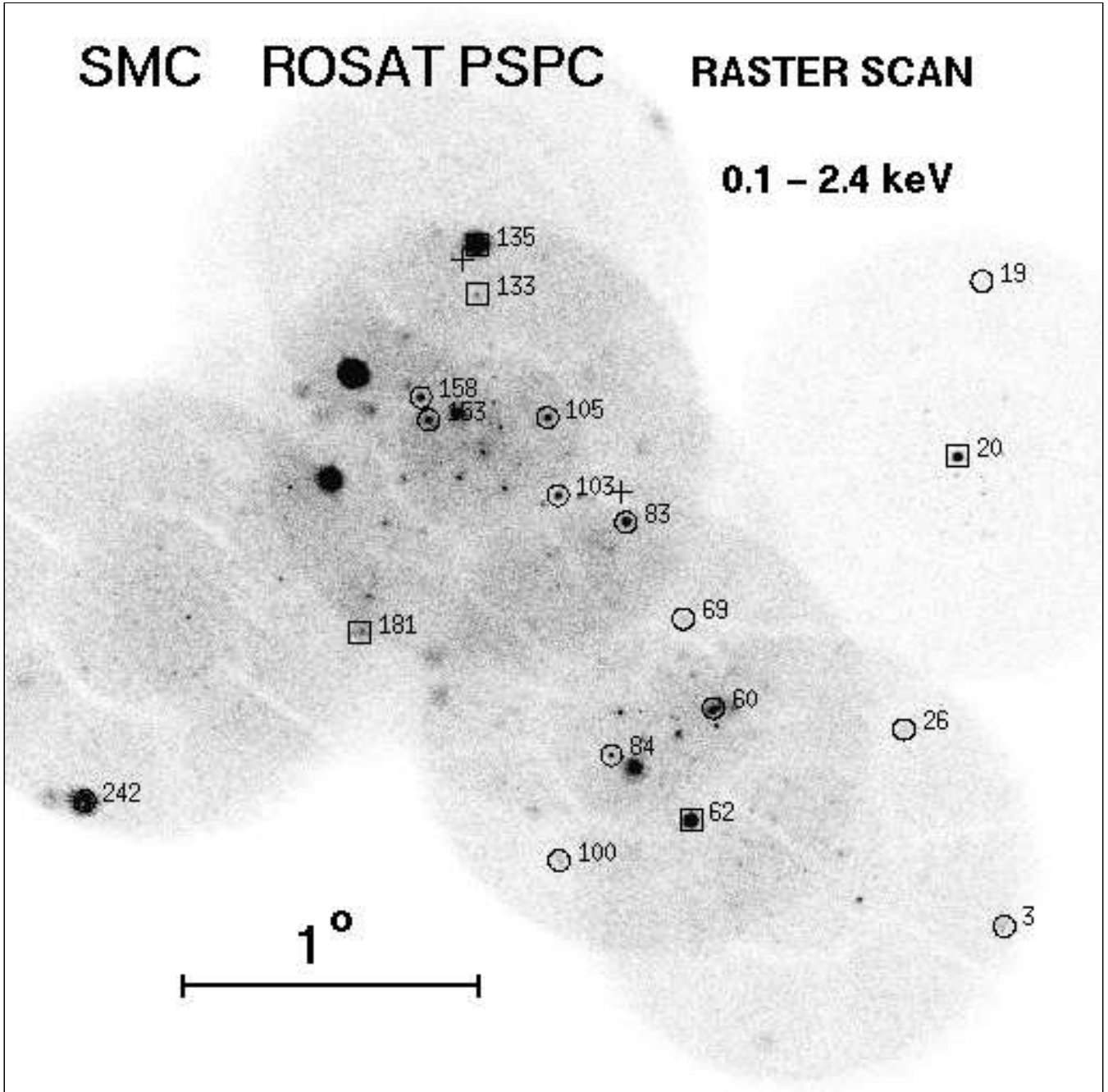
Fig. 1. Image (0.1-2.4 keV) of the SMC pointings A,B,C,D,E,F,G,X and Y (cf. Table 1). The center of the image is at R.A.(2000) = $1^h 00^m$, Decl.(2000) = $-73^d 00^m$. The 13 candidate hard X-ray binaries in the SMC are marked with a circle and an internal catalog number is given (cf. Table 3). The 5 candidate supersoft sources in the SMC are marked with a square and an internal catalog number is given (cf. Table 4). The positions of the two transient X-ray binary sources SMC X-3 (close to source #83) and RX J0059.2-7138 (close to source #135) which have not been detected in the analysed pointings are marked with a cross.

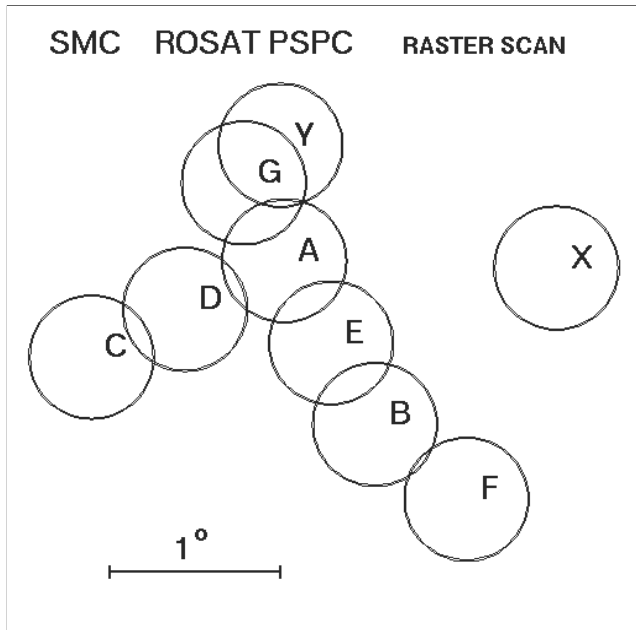inner 20′ of the detector for all pointings is shown in Figure 2.

Fig. 2. Image of the inner 20′ of all pointings on the SMC discussed in the paper. The same field of view and projection is chosen as in Figure 1.

2.3. Detections and Count Rates

A sophisticated procedure and technique has been used to generate a catalog of X-ray detections from the 9 pointings listed in Table 1. This procedure is described in detail in a separate paper. A maximum likelihood detection algorithm in *EXSAS* (Zimmermann et al. 1993) has been used to determine the position of the source and the counts in the standard *ROSAT* energy bands Soft=(channel 11-41, roughly 0.1-0.4 keV), Hard=(channel 52-201, roughly 0.5-2.1 keV), Hard1=(channel 52-90, roughly 0.5-0.9 keV), Hard2=(channel 91-201, roughly 0.9-2.0 keV). Hardness ratios HR1 and HR2 have been calculated from the counts in the bands HR1=(H-S)/(H+S) and HR2=(H2-H1)/(H1+H2). The result is given in Table 3 and Table 4. Upper limit counts have been calculated by a maximum likelihood algorithm (cf. Pollock et al. 1981). The time dependent X-ray count rate of the X-ray binaries in the *ROSAT* band (0.1-2.4 keV) has been studied for time scales in excess of individual observation intervals (typically 10 minutes to 1 hour). Variability on shorter time scales has not been looked for with the exception of SMC X-1 where two X-ray bursts (or flares) have been discovered and studied. Most sources have been covered by more than one pointing and a search for long-term (∼half a year) variability became possible.

2.4. Selection Criteria for Hard Sources

The selection criteria for hard X-ray binaries were set such that, first of all they must comprise all known hard X-ray binaries in the SMC and second they must cover all sources with an X-ray luminosity above ∼3×10^{35}erg s^{-1} (0.1 - 2.4 keV) and detectable temporal variability. The X-ray luminosity has been determined from the X-ray counts applying a conversion factor

$$Luminosity[erg/s] = countrate[cts/s] \times 1.67 \times 10^{37},$$

appropriate for a thermal bremsstrahlung spectrum of temperature 2 keV, a galactic absorbing column density of 3×10^{20}cm^{-2} and a SMC intrinsic absorption column of 4×10^{21}cm^{-2} (cf. absorbing columns given in Figure 7 and the smaller X-ray absorption in the SMC per H-atom discussed below) and assuming a distance to the SMC of 65 kpc (cf. Wang & Wu 1992). As many of the SMC X-ray binaries may be (and indeed turn out to be) heavily absorbed (cf. Table 6), a rather large SMC intrinsic absorption of 4×10^{21} cm^{-2} seems to be justified. But it introduces some uncertainty in the luminosity threshold due to the unknown intrinsic luminosity. On the other hand a simple conversion from X-ray count rates to luminosities and assuming an a priori absorption (like the galactic foreground value) would just give a lower limit on the luminosity.

Table 2. Selection criteria for spectrally hard and soft X-ray binary candidates

Quantity	Selection criterion	
	hard source	soft source
HR1	≥ 0.5	≤ -0.8
HR2	≥ 0.0	$-$
count rate	> 0.015 s^{-1}	> 0.015 s^{-1}
extent likelihood	< 50	$-$
time variability	$>$ hours	$-$

We considered all sources fulfilling the selection criteria listed in Table 2. These sources have a value for the hardness ratio HR1 $\geq +0.5$ (excluding spectrally softer sources like stars) a count rate above 0.015 counts s^{-1} and a likelihood of extension <50 (determined by a standard maximum likelihood detection, Zimmermann et al. 1993). The extent selection has been applied in order to discriminate supernova remnants or other extended structure from point like sources. Another criterion (HR2 < 0) has been introduced in order to discriminate against spectrally softer sources (e.g. AGNs). Errors in the hardness ratios HR1 and HR2 have not been considered as they turn

Table 1. Field centers, observation intervals and exposure times of pointed observations on SMC

Field	R.A.(2000)	Decl.(2000)	time start [UT]	time end [UT]	exposure [ksec]
A1	$0^h 58^m 12.0^s$	$-72^d 16^m 48^s$	8-Oct-91 – 03:10	9-Oct-91 – 02:47	17.0
A2	$0^h 58^m 12.0^s$	$-72^d 16^m 48^s$	17-Apr-92 – 17:07	27-Apr-92 – 16:34	9.7
B1	$0^h 50^m 45.5^s$	$-73^d 13^m 48^s$	9-Oct-91 – 03:03	9-Oct-91 – 04:43	1.4
B2	$0^h 50^m 45.5^s$	$-73^d 13^m 48^s$	15-Apr-92 – 15:40	24-Apr-92 – 18:17	22.7
C	$1^h 13^m 24.0^s$	$-72^d 49^m 12^s$	16-Oct-91 – 07:33	19-Oct-91 – 23:32	22.1
D	$1^h 05^m 55.2^s$	$-72^d 33^m 36^s$	10-Apr-93 – 11:54	14-Oct-93 – 16:54	30.9
E	$0^h 54^m 28.7^s$	$-72^d 45^m 36^s$	9-May-93 – 07:17	12-May-93 – 20:14	16.8
F1	$0^h 42^m 55.2^s$	$-73^d 38^m 24^s$	5-Dec-92 – 23:58	8-Dec-92 – 01:40	9.7
F2	$0^h 42^m 55.2^s$	$-73^d 38^m 24^s$	5-Apr-93 – 06:12	26-Apr-93 – 23:31	8.3
G1	$1^h 01^m 16.7^s$	$-71^d 49^m 12^s$	6-Dec-92 – 09:33	6-Dec-92 – 13:10	3.6
G2	$1^h 01^m 16.7^s$	$-71^d 49^m 12^s$	7-Oct-93 – 20:06	10-Oct-93 – 14:46	4.6
X1	$0^h 37^m 19.2^s$	$-72^d 14^m 24^s$	28-Apr-92 – 12:50	3-Jun-92 – 17:58	6.4
X2	$0^h 37^m 19.2^s$	$-72^d 14^m 24^s$	2-Oct-93 – 10:15	9-Oct-93 – 06:06	1.7
Y1	$0^h 58^m 33.5^s$	$-71^d 36^m 00^s$	29-Mar-93 – 08:07	30-Mar-93 – 21:10	5.2
Y2	$0^h 58^m 33.5^s$	$-71^d 36^m 00^s$	1-Oct-93 – 14:06	9-Oct-93 – 19:19	7.2

out to be small for the considered count rates. Two sources have been rejected as they coincide with struts of the detector system. 13 sources fulfilled these criteria (cf. Table 3 and Figure 1). Of the seven sources known from *Einstein* observations (with the catalog numbers 60, 83, 84, 103, 105, 153, and 242, cf. Table 3) only SMC X-1 (number 242) and 1 E0050.1-7248 (RX J0051.8-7231, number 83) have been considered by Wang & Wu (1992) as X-ray binaries. Sources with the indices 103, 105, and 153 will be discussed in section 4.4. Six sources (with catalog numbers 3, 19, 26, 69, 100, and 158) have not been seen with *Einstein* . One of them is SMC X-2, a Be type transient, the other five are *ROSAT* discoveries and good candidate X-ray binaries.

Finally accepted sources had to show variability in time detectable either within one observation with time scales of minutes to days or from one pointing to another with a time scale of about half a year. The latter time scale allowed us to discover two X-ray transients not seen with *Einstein* . All new hard X-ray binary candidates still lack an optical identification, but optical identification work is in progress (cf. sections 3.4.3 and 3.4.5). Optical identification will clarify that we did not confuse them with variable background AGNs. The seven accepted sources (showing time variability) and the six rejected sources (due to missing time variability) are listed in Table 3 and are marked in Figure 1.

2.5. Candidate supersoft X-ray sources

To search for candidate supersoft sources we selected sources with HR1 $<$ -0.8 and a count rate $\geq$ 0.015 counts s^{-1}. We found five candidates. Four of these

were presented by Kahabka et al. (1994). The new candidate is RX J0103.8-7254. A correlation with the star CPD-73 2349 as stated by Wang & Wu (1992) is in error. There are two ot three not too faint blue stars in the error circle (M.Pakull, private communication). The X-ray source has also been detected by the *ROSAT WFC* and is contained in the *2RE* source catalog (Pye et al. 1995). This would be in favor for a galactic nature of the object with a comparatively low foreground absorbing column density. We searched in our SMC point source catalog (Kahabka & Pietsch 1996) for CAL 87 like candidates, which appear to be hotter than the ordinary SSS and have HR1>0 and HR2<-0.6 and found none.

3. Observational results of individual sources

We report about the results obtained from the *RASS* and the pointed *ROSAT* observations. The *RASS* observations are typically a factor of 10 less deep in source flux and besides SMC X-1 no SMC X-ray binary was detected. We can only give upper limit count rates for the sample of binaries found from previous observations or during the deep pointed observations.

The result of the selection defined in the previous chapter and applied to the pointed data is given in Table 3 to Table 5. We reject six hard X-ray binary candidates (due to amissing time variability) and select seven candidates (see Table 3). From the sample of supersoft candidates we reject 1 source and select 4 sources (see Table 4). Finally we give in Table 5 upper limits to count rates for those pointings where the discovered transient hard X-ray sources have not been detected and give upper limits to count rates for two previously recorded transient hard

X-rays sources contained in the field of view of our observations. The result of detailed spectral fitting of the brighter hard X-ray sources is given in Table 6. For the supersoft sources the result of the spectral modeling has already been published in Kahabka et al. (1994). A compilation (catalog) of the presently known and published sample of SMC X-ray binaries and candidates is given in Table 10.

3.1. Temporal Analysis

The two recorded transients SMC X-3 and the 2.8 s transient RX J0059.2-7138 recently discovered by Hughes (1994) have not been detected in our pointings. The upper limit luminosities of $\sim 9 \times 10^{34}$ erg s^{-1} and $\sim 6 \times 10^{34}$ erg s^{-1} respectively (in case of a SMC X-2 like spectrum, cf. Table 5) are consistent with a Be type transient nature of these two sources.

Light curves have been generated for the five brightest transient and persistent hard X-ray binaries in the energy interval 0.1-2.4 keV. One data point has been drawn per observation interval (of duration $\sim$10 min to 1 hour).

SMC X-1 has been observed during one full binary orbit (cf. Figure 3 and Figure 8). The observation took place during a low intensity state. It starts with a mean count rate of 0.16 counts s^{-1} covering an extended X-ray eclipse. The source then showed a flare like event with an increase in count rate by a factor of 10 up to 1.5 counts s^{-1} in the peak (cf. Figure 8). The full rise of the peak has not been observed but an increase by a factor of 2 in intensity occurred within 200 seconds. The source then showed a flare with a rise time of about 6 hours and a second intensity increase (at orbital phase $\sim$0.34) with a similar peak count rate as in the first flare. The separation of the two intensity spikes is ~ 9.6 hours. The second peak has not been seen during the rise time but during a plateau (of ~ 250 sec duration). In the last part of the observation the intensity declines from ~ 0.5 counts s^{-1} to the initial observed level of ~ 0.2 counts s^{-1}.

The X-ray transient SMC X-2 has been discovered with *ROSAT* in its second outburst after *SAS-3* (Clark et al. 1978) in pointing B1 for 1.8 hours and with a mean count rate of 0.39 counts s^{-1} (cf. Figure 3). Half a year after this *ROSAT* observation the X-ray source was no longer detected. A 2σ upper limit to the count rate of 5.8×10^{-4} counts s^{-1} has been deduced indicating variability by a factor $> 6 \times 10^3$.

The source RX J0051.8-7231 has already been discovered in *Einstein* observations (*Einstein* name 1E 0050.1-7248, Wang & Wu 1992). It was in the field of view of the *ROSAT* pointings A1, A2 and E but has only been detected in pointing E which indicates intensity variations by at least a factor of 35 (cf. Table 3 and Table 5). In pointing E an increase in intensity by a factor of three has been observed within three days (cf. Figure 3).

RX J0052.1-7319 has been discovered in *Einstein* observations (*Einstein* name 1E 0050.3-7335, Wang & Wu 1992). During *ROSAT* observations the source has been found to be variable (cf. Figure 4). From *Einstein* observations no variability has been reported. The source has been detected in pointing B2 with a mean count rate of 0.089 ± 0.02 counts s^{-1}.

A new X-ray transient (RX J0101.0-7206) has been discovered with *ROSAT* at the north-eastern boundary of the HII region N66. The transient has been seen in outburst in pointing A1 for 22 hours (cf. Figure 3). Half a year later the X-ray source has no longer been detected. A 2σ upper limit count rate of 1.46×10^{-3} counts s^{-1} was deduced indicating a variability by a factor of > 33 (cf. Table 3 and Table 5).

Another highly variable X-ray source RX J0049.1-7250 was discovered with *ROSAT* north west of the supernova remnant N 19. The variability from pointing B1 to B2 was a factor of 12 in the (0.5-2.0 keV) band (cf. Figure 4). The source is highly absorbed (cf. Table 6) and has not been detected in the soft band.

RX J0032.9-7348 is a candidate for a variable X-ray binary at the south-eastern border of the SMC. It showed a count rate of 0.122 counts s^{-1} in pointing F2. In another pointing taken $\sim$0.4 years before the source was about a factor of 6 weaker.

3.2. Spectral Analysis

A thermal bremsstrahlung spectral fit has been applied to the X-ray spectra. For the absorption (in our Galaxy and the SMC) two different abundances have been used. A spectral fit has been performed first assuming cosmic abundances and second cosmic abundances for a galactic contribution of 3×10^{20} cm^{-2} and reduced metallicities (by a factor of about 7, cf. Pagel 1993) for the additional SMC contribution).

The model of reduced metallicities in the absorbing opacities gives higher hydrogen column densities (by $\sim$70%), somewhat higher bremsstrahlung temperatures (of $\sim$25%) and lower X-ray luminosities (by $\sim$25%). The result of the spectral fitting is detailed in Table 6. We give the exposure time, the best fit thermal bremsstrahlung temperature (with 95% confidence errors), the absorbing hydrogen column density (with 95% confidence errors), the unabsorbed and absorbed X-ray luminosity (0.15-2.4 keV), the chi-squared and the degrees of freedom for the fit. In Figure 5 and Figure 6 the 68, 95, 99 % confidence parameter contours for low metal abundance absorption within the SMC versus thermal bremsstahlung temperature for six SMC hard X-ray binaries is shown. With the exception of SMC X-1 the *ROSAT PSPC* can limit the thermal bremsstrahlung temperature only at the lower bound. In our low-state observation SMC X-1 has a temperature below $\sim$5 keV (95% confidence). The best-fit temperature is for all sources above 1 keV and for
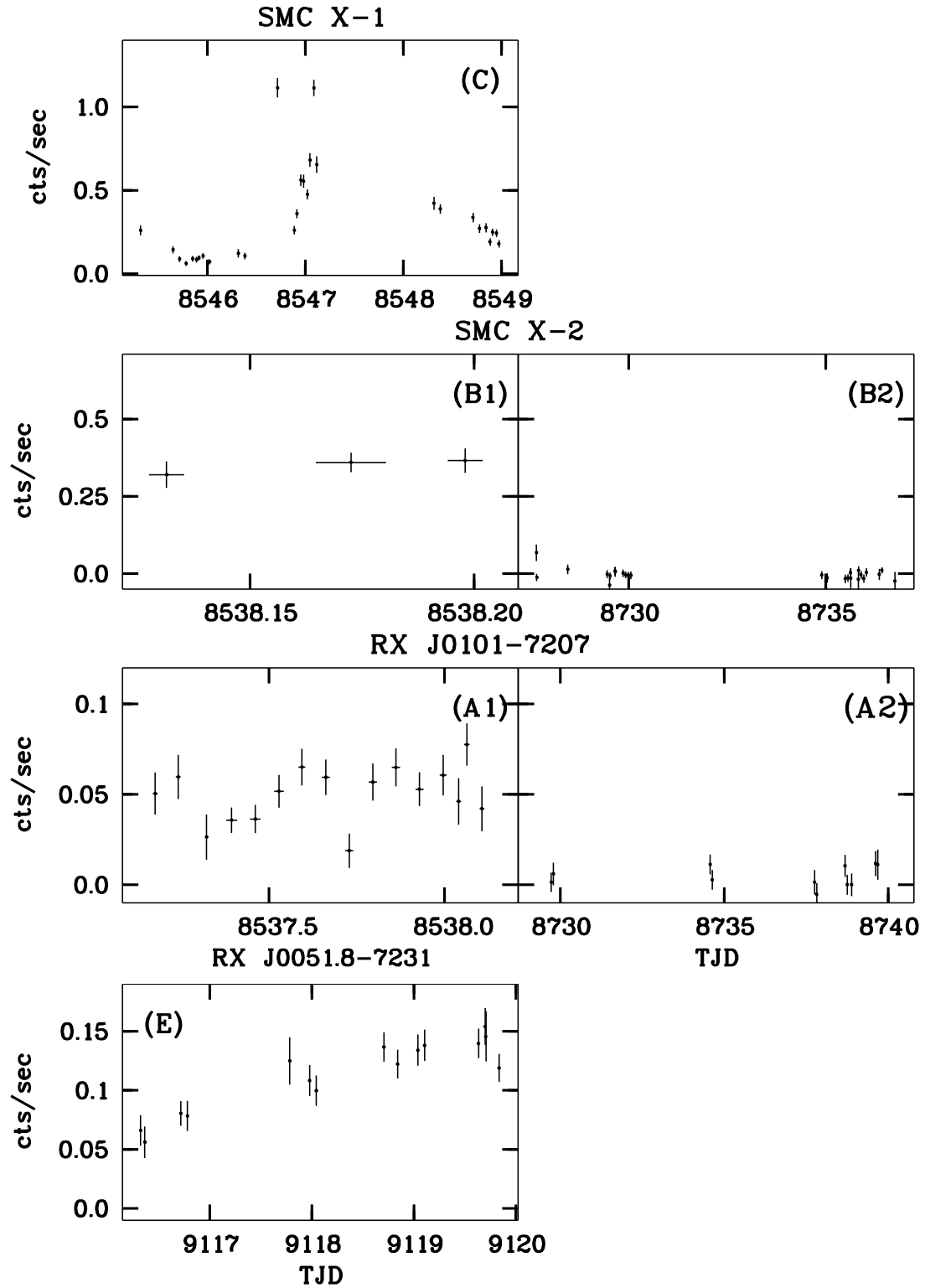
Fig. 3. Light curves (0.1 - 2.4 keV) of SMC X-1 (pointing C), SMC X-2 (pointings B1 and B2), RX J0101.0-7206 (pointings A1 and A2) and RX J0051.8-7231 (pointing E). For each observation interval one data point is drawn. Time TJD is given (JD - 2440000.5).

Table 3. Equatorial coordinates, error radius, count rate (0.1-2.4 keV), hardness ratio HR1 and HR2, off-axis angle for the 7 accepted (time variable) and the 6 rejected (showing no time variability) candidate hard X-ray binaries in the SMC. The parameters are deduced for each source separately and may differ (slightly) from the parameters in the SMC point source catalog (Kahabka & Pietsch 1996).

catalog number	Source name	R.A.(2000)	Decl.(2000)	Err.rad.[b] [arcsec]	count rate [sec^{-1}]	hardness ratio HR1/HR2	off-axis [arcmin]	Remarks[a]
				accepted X-ray binaries (variable in time)				
242	SMC X-1	$1^h17^m02.2^s$	$-73^d26^m33^s$	65	0.373±0.003	+1 / 0.317±0.007	41	63 [2]
100	SMC X-2	$0^h54^m31.3^s$	$-73^d40^m54^s$	62	0.390±0.022	0.971±0.028 / 0.637±0.043	32	–
3	RX J0032.9-7348	$0^h32^m55.1^s$	$-73^d48^m11^s$	62	0.122±0.005	+1/ 0.546±0.038	43	–
69	RX J0049.1-7250	$0^h49^m04.6^s$	$-72^d50^m53^s$	22	0.042±0.008	+1/ 0.836±0.100	24	–
83	RX J0051.8-7231	$0^h51^m53.0^s$	$-72^d31^m45^s$	11	0.112±0.003	0.951±0.011 / 0.479(0.023)	18	27 [2]
84	RX J0052.1-7319	$0^h52^m11.3^s$	$-73^d19^m13^s$	11	0.0214±0.011	0.941±0.015/ 0.612±0.014	8	29 [2]
158	RX J0101.0-7206	$1^h01^m03.2^s$	$-72^d06^m57^s$	5	0.048±0.002	0.882±0.036/ 0.472±0.037	16	–
				rejected X-ray binaries (missing time variability)				
19	RX J0036.9-7138	$0^h36^m59.9^s$	$-71^d38^m07^s$	68	0.0246±0.0029	+1 0.383±0.116	36	–
26	RX J0038.6-7310	$0^h38^m36.3^s$	$-73^d10^m22^s$	65	0.0317±0.0025	+1/ 0.393±0.075	34	–
60	RX J0047.5-7308	$0^h47^m30.8^s$	$-73^d08^m46^s$	63	0.0351±0.0021	+1/ 0.209±0.057	38	[1], 16 [2]
103	RX J0054.9-7226	$0^h54^m57.3^s$	$-72^d26^m39^s$	11	0.0273±0.0012	+1/ 0.554±0.036	18	35 [2]
105	RX J0055.4-7210	$0^h55^m29.2^s$	$-72^d10^m53^s$	11	0.0247±0.0010	+1/ 0.359±0.040	14	36 [2]
153	RX J0100.7-7211	$1^h00^m43.4^s$	$-72^d11^m34^s$	11	0.0240±0.0011	0.969 0.329±0.041	13	45 [2]

a) [1] SNR 0045-734. [2] Source number from catalog of discrete X-ray sources of Wang & Wu (1992).
b) For sources with off-axis angles in excess of $\sim 30'$ a systematic error in position of 1arcmin has been added quadratically to the positional error determined with the maximum likelihood algorithm.

RX J0051.8-7231 (WW 27) above 10 keV. Temperatures above $\sim$10 keV are typical for HMXBs and temperatures below $\sim$10 keV for LMXBs. This may be due to reprocessed X-rays determining the spectra of the latter class. One has to note that the spectrum of SMC X-1 in our low-state observation may be dominated by reprocessed radiation. The high absorbing hydrogen column deduced from nearly all X-ray spectra can be explained by matter located in the SMC and in part within the individual binary system. In Figure 7 the positions of the discussed X-ray binaries are drawn on a HI column density map deduced from 21-cm data (Luks 1994). This illustrates the largest SMC column expected to be deduced from the X-ray spectra of these sources.

In Table 7 the hydrogen column densities of the X-ray sources as deduced from a spectral fit are given together with the values found from the HI map (smoothed with a Gaussian σ of 8'). One has to admit that the resolution of the radio map with $\sim$ 15' is rather coarse. We also refer to the work of Bessell (1991) (and references given therein) for a discussion of the SMC foreground and the SMC intrinsic reddening.

Table 4. Equatorial coordinates, error radius, count rate (0.1-2.4 keV), hardness ratio HR1 and HR2, off-axis angle for the 4 selected and 1 candidate supersoft source.

catalog number	Source name	R.A.(2000)	Decl.(2000)	Err.rad. [arcsec]	count rate [sec^{-1}]	hardness ratio HR1/HR2	off-axis [arcmin]	Remarks[a]
				selected supersoft sources				
20	1E 0035.4-7230	$0^{\mathrm{h}}37^{\mathrm{m}}19.5^{\mathrm{s}}$	$-72^{\mathrm{d}}14^{\mathrm{m}}08^{\mathrm{s}}$	11	0.504±0.010	-0.966/-0.954	0.2	variable
135	1E 0056.8-7146	$0^{\mathrm{h}}58^{\mathrm{m}}37.2^{\mathrm{s}}$	$-71^{\mathrm{d}}35^{\mathrm{m}}56^{\mathrm{s}}$	11	0.356±0.007	-0.993/-1	0.3	PN
62	RX J0048.4-7332	$0^{\mathrm{h}}48^{\mathrm{m}}16.3^{\mathrm{s}}$	$-73^{\mathrm{d}}31^{\mathrm{m}}45^{\mathrm{s}}$	11	0.188±0.003	-0.973/-0.923	21	symb. nova
133	RX J0058.6-7146	$0^{\mathrm{h}}58^{\mathrm{m}}35.8^{\mathrm{s}}$	$-71^{\mathrm{d}}46^{\mathrm{m}}02^{\mathrm{s}}$	13	0.0256±0.0025	-0.994/-1	10	transient
				candidate supersoft sources				
181	RX J0103.8-7254	$1^{\mathrm{h}}03^{\mathrm{m}}53.4^{\mathrm{s}}$	$-72^{\mathrm{d}}54^{\mathrm{m}}49^{\mathrm{s}}$	15	0.0218	-1/0.0	23	[1]

a) source [1] correlates with the *EXOSAT* source EXO 0102.3-7318 (cf. Table 2B from Wang & Wu 1992). The source is not yet optically identified.

Table 5. *ROSAT* pointed 2σ upper limit count rates (0.1-2.4 keV) and (0.5-2.0 keV) for the detected and the recorded transient X-ray sources. The count rate for a detection is given for RXJ0049.1-7250 in the (0.5-2.0 keV) band.

Source name	2σ upper limit count rate [10^{-3} counts s^{-1}]		time start	time end	offax [arcmin]	field
	(0.1-2.4 keV)	(0.5-2.0 keV)				
			detected transient X-ray sources			
SMC X-2	0.58	0.66	15-Apr-92 − 15:40	24-Apr-92 − 18:17	31.5	B2
RX J0049.1-7250	2.85	3.50(±0.59)	15-Apr-92 − 15:40	24-Apr-92 − 18:17	24.0	B2
RX J0051.8-7231	2.70	2.69	8-Oct-91 − 03:03	9-Oct-91 − 04:47	32.3	A1
	3.16	3.04	17-Apr-92 − 17:07	27-Apr-92 − 16:34	32.3	A2
RX J0052.1-7319	2.21	1.59	9-Oct-91 − 03:03	9-Oct-91 − 04:43	8.2	B1
RX J0101.0-7206	1.46	0.62	17-Apr-92 − 17:07	27-Apr-92 − 16:34	16.4	A2
	1.44	1.37	6-Dec-92 − 09:33	6-Dec-92 − 13:10	17.8	G1
	2.58	2.76	7-Oct-93 − 20:06	10-Oct-93 − 14:45	17.8	G2
			recorded but not detected transient X-ray sources			
SMC X-3	1.73	1.17	8-Oct-91 − 03:10	9-Oct-91 − 02:47	29.0	A1
	0.59	0.42	17-Apr-92 − 17:07	27-Apr-92 − 16:34	29.0	A2
	1.48	0.55	9-May-93 − 07:26	12-May-93 − 20:10	22.5	E
RX J0059.2-7138	-	0.54	8-Oct-91 − 03:10	9-Oct-91 − 02:47	38.2	A1
	-	1.23	17-Apr-92 − 17:07	27-Apr-92 − 16:34	38.2	A2
	2.04	0.71	6-Dec-92 − 09:33	6-Dec-92 − 13:10	14.2	G1
	1.05	0.48	7-Oct-93 − 20:06	10-Oct-93 − 14:46	14.2	G2
	1.04	0.51	29-Mar-93 − 08:07	30-Mar-93 − 21:03	4.2	Y1
	0.91	0.25	1-Oct-93 − 14:06	9-Oct-93 − 19:19	4.2	Y2

3.3. All-Sky Survey Observations

The field of the SMC (where X-ray binaries have been detected) has been observed from about 21 October 1990 till 31 October 1990. Of the sample of spectrally hard X-ray binaries only SMC X-1 has been detected during this observation and we briefly report about this observation. For the other hard X-ray binaries and candidate hard X-ray binaries only upper limit count rates can be given for this epoch. The observations of the supersoft X-ray binaries during the *RASS* have been reported in Kahabka et al. (1994).
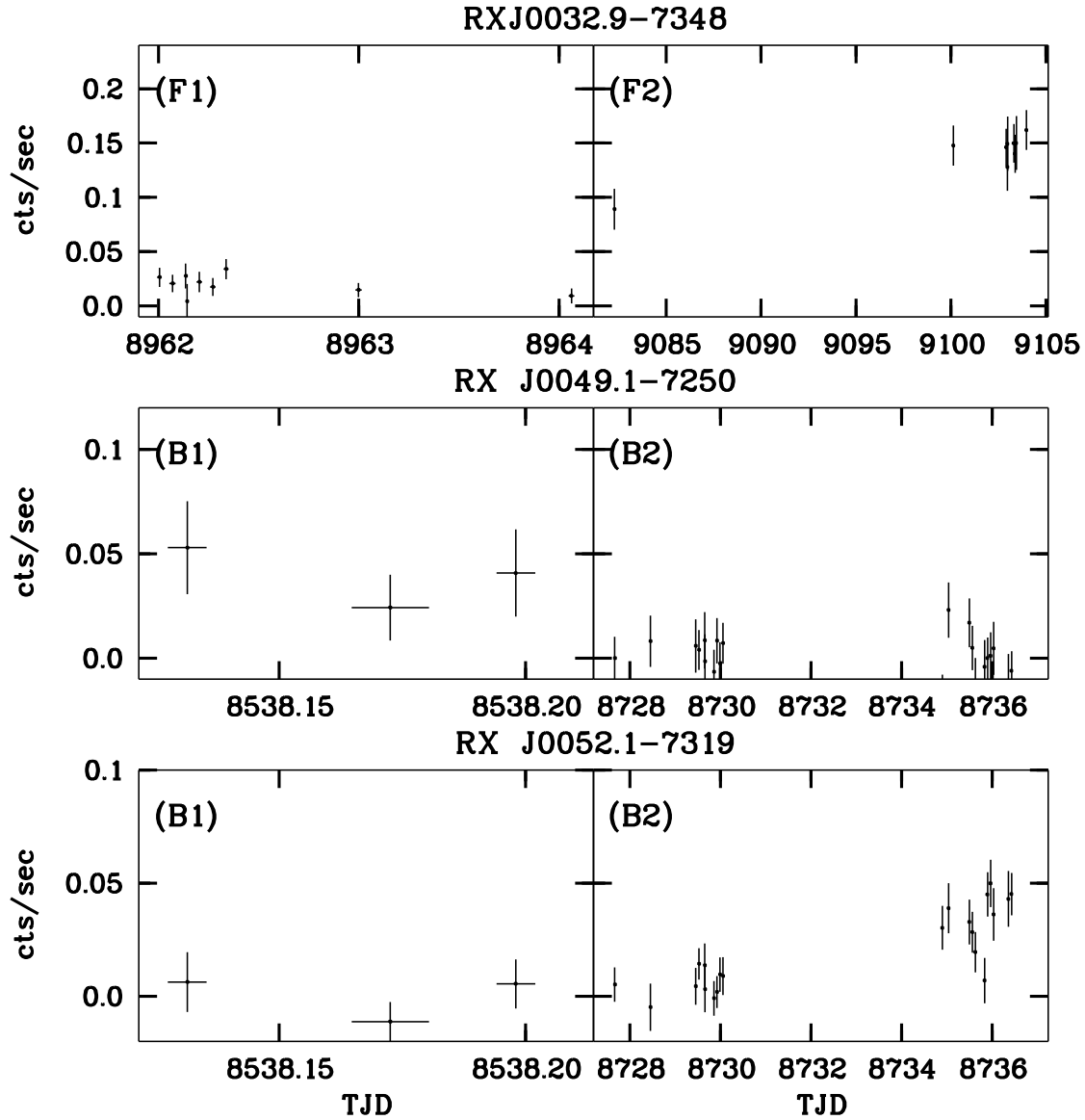
Fig. 4. Light curves (0.5-2.4 keV) of RX J0032.9-7348 (pointings F1 and F2) and light curves (0.1-2.4 keV) of RX J0049.1-7250 (pointings B1 and B2) and RX J0052.1-7319 (pointings B1 and B2). For each observation interval one data point is drawn. Time is given in TJD (JD - 2440000.5).

3.3.1. SMC X-1

SMC X-1 has been observed from 23 October 1990 (20:40 UT) till 28 October 1990 (9:33 UT) and stayed in a low-state during the whole period with a mean count rate of 0.595 ± 0.074 counts s^{-1} (Kahabka & Pietsch 1993). In Figure 8 (first panel) the light curve (with a binsize of 20 sec) is shown. It covers almost exactly a full binary orbital cycle of 3.89 days. The observation starts with the eclipse phase and enters then (during orbital phases 0.3-0.6) into a similar flaring phase as has been seen in the pointed observations (cf. Figure 8, second panel) but here with much lower statistical significance. A thermal bremsstrahlung fit with two absorption components (a galactic contribution of 3×10^{20} atoms cm^{-2} and a variable SMC intrinsic component with reduced metallicities, factor 7) applied to the RASS spectrum of SMC X-1 gives spectral parameters (kT$\sim$ 2 keV, N$_{\mathrm{H}}\sim 3 \times 10^{21}$ atoms cm^{-2}) which are consistent (within the errors) with the parameters found for the pointed low-state spectrum.

Table 6. Spectral parameters of a thermal bremsstrahlung fit for the 7 X-ray binaries in the SMC. Thermal bremsstrahlung temperature kT_{th} (keV), galactic absorbing column density ($10^{21}cm^{-2}$), X-ray luminosity L_x (0.15 - 2.4 keV, $10^{37}erg/s$, 65 kpc), absorbed X-ray luminosity L_{abs} (0.15 - 2.4 keV, $10^{37}erg/s$, 65 kpc, excluding a galactic contribution of $3. \times 10^{20}cm^{-2}$), χ_2 and degrees of freedom (DOF) of fit, and pointing.

Source	kT_{th} [keV]	N_H [$10^{21}cm^{-2}$]	L_x [$10^{37}erg/s$]	L_{abs} [$10^{37}erg/s$]	χ_2	DOF	Field
		galactic opacities					
SMC X-1	1.81(-0.71,+0.82)	1.41(-0.41,+0.43)	2.57	1.42	54	43	C
SMC X-2	10(-8.5)	2.93(-1.4,+7)	2.67	1.38	10	11	B1
RX J0032.9-7348	10(-9)	2.5(-1,+3)	0.25	0.13	20	19	F2
RX J0049.1-7250	1.1	13	2.5	1.6	1.5	5	B1
	1.0	21	0.32	0.2	5.0	7	B2
RX J0051.8-7231	10(-8.5)	1.17(-0.4,+1.6)	0.509	0.350	45	49	E
RX J0052.1-7319	5.4	3.34(-2,+17)	0.162	0.126	10	11	B2
RX J0101.0-7206	2.23(-1.5)	1.63(-1.2,+3.4)	0.184	0.0804	17	18	A1
		SMC opacities (galactic contribution of 0.3×10^{21} cm^{-2} subtracted)					
SMC X-1	1.94(-0.67,+2.71)	2.38(-0.9,+0.98)	1.77	1.34	49	43	C
SMC X-2	10(-9)	5.70(-1.7,+12)	2.29	1.28	13	11	B1
RX J0032.9-7348	10(-9)	5.3(-4,+8)	0.26	0.14	19	19	F2
RX J0049.1-7250	8.0	33	8×10^3	6×10^3	1.5	5	B1
	24	41	1.3	1.0	5.1	5	B2
RX J0051.8-7231	10(-8)	1.87(-1.1,+2.6)	0.492	0.349	54	49	E
RX J0052.1-7319	17	7.05	0.137	0.109	9.7	11	B2
RX J0101.0-7206	3.46(-3.46,+6.5)	2.46(-2)	0.152	0.0824	17	18	A1

3.3.2. Upper Limit Count Rates for the not detected X-ray Binaries

The transients SMC X-2 and SMC X-3 have not been in outburst during the *RASS*. The observation time intervals and the upper limit count rates of these two transients and of the other candidate X-ray binaries listed in Table 3 are given in Table 5.

3.4. Pointed observations

We discuss in this section the new sample of SMC X-ray binaries, compiled after the extensive pointed observations with *ROSAT* . This should give a less biased view if compared to the limited sensitivity of the instrumentation before. The available *ROSAT PSPC* pointed data towards the SMC, which have been analysed in this work allowed a by about a factor of ∼10 deeper search for candidate X-ray binaries than was possible with the *RASS* data. In Table 9 we give for those sources, which have been found during *Einstein* and *ROSAT* observations the *Einstein* and *ROSAT* name. We will discuss the individual SMC binary systems in detail. The complete list of known SMC X-ray binaries and candidate X-ray binaries is given in Table 10.

3.4.1. The high-mass binary system SMC X-1

SMC X-1 has been detected during a rocket flight (Price et al. 1971). The discovery of eclipses by the *UHURU* satellite with a period of 3.89 days (Schreier et al. 1972) established the binary nature of the source. The optical counterpart has been identified as a B0I supergiant (Sk 160) (Webster et al. 1972, Liller 1973). Optical photometry indicated the presence of an accretion disk influencing the optical light curve (van Paradijs & Zuiderwijk 1977). X-ray low- and high-intensity states have been observed (Schreier et al. 1972, Tuohy & Rapley 1975, Seward & Mitchell 1981, Bonnet-Bidaud & van der Klis 1981). Angelini et al. (1991) report about the discovery of an X-ray burst from SMC X-1. This burst may be related to the type II bursts observed from the Rapid Burster, which are interpreted as resulting from an instability in the accretion flow (Lewin, van Paradijs and Taam 1993). A ∼60 day quasi-periodicity in the X-ray flux has been suggested by Gruber & Rothschild (1984) from *HEAO-1 (A4)* data. Whitlock & Lochner (1994) generated a 7 year light curve from *Vela 5* data which showed the source only once in a prolonged high-state (of duration ∼100 days). Binary orbital parameters have been established by Prim-
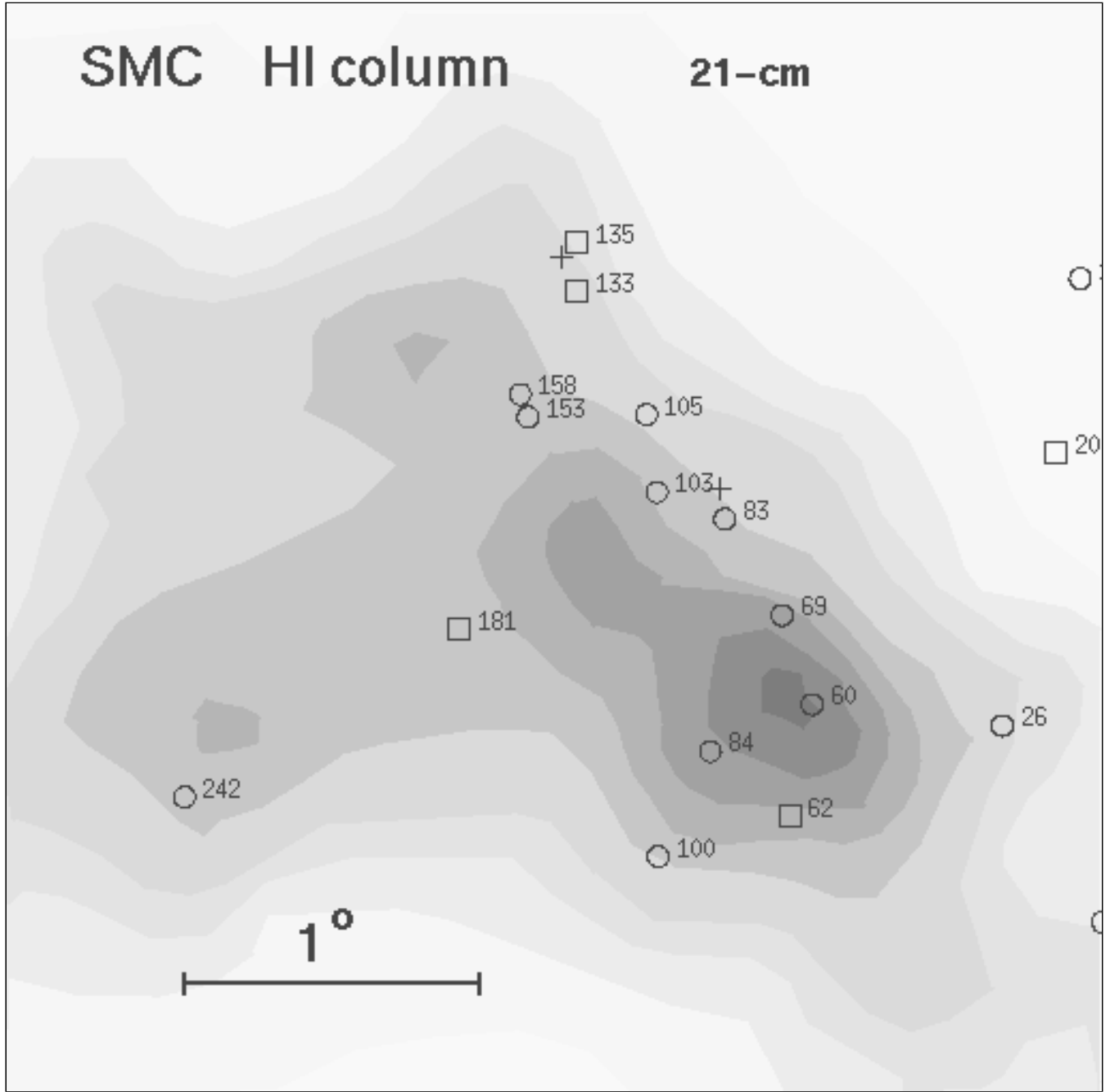
Fig. 7. 21-cm HI contour map (reproduced from Luks 1994) with the positions of the candidate supersoft X-ray binaries (square) and of the hard X-ray binaries (circle) drawn (cf. Figure 1). N_H contours are 70,60,50,40,30,20,15,10,5 $\times 10^{20}$ hydrogen atoms cm^{-2}. The darkest shading refers to the largest hydrogen column.

ini, Rappaport & Joss (1977). A decay in the binary orbit with $\dot{P}_{orb}/P_{orb} = (-3.36 \pm 0.02) \times 10^{-6} \, \mathrm{yr}^{-1}$ was reported by Levine et al. (1993). They propose that this is caused by tidal interaction between the orbit and the rotation of the companion star (asynchronism) due to the evolutionary expansion of the companion star Sk 160 which is assumed to be in the Hydrogen burning phase.

During our *ROSAT* pointed observations covering one full binary orbit of SMC X-1 the source was in a low intensity state. It was in the beginning observed during an extended and shallow eclipse (with residual flux at zero orbital phase and a mean luminosity of $\sim 8 \times 10^{36} \mathrm{erg \, s}^{-1}$). It then passed into a flaring state with two additional bursts (separated by about 10 hours). The increase in intensity from the shallow eclipse to the peak of the first short du-
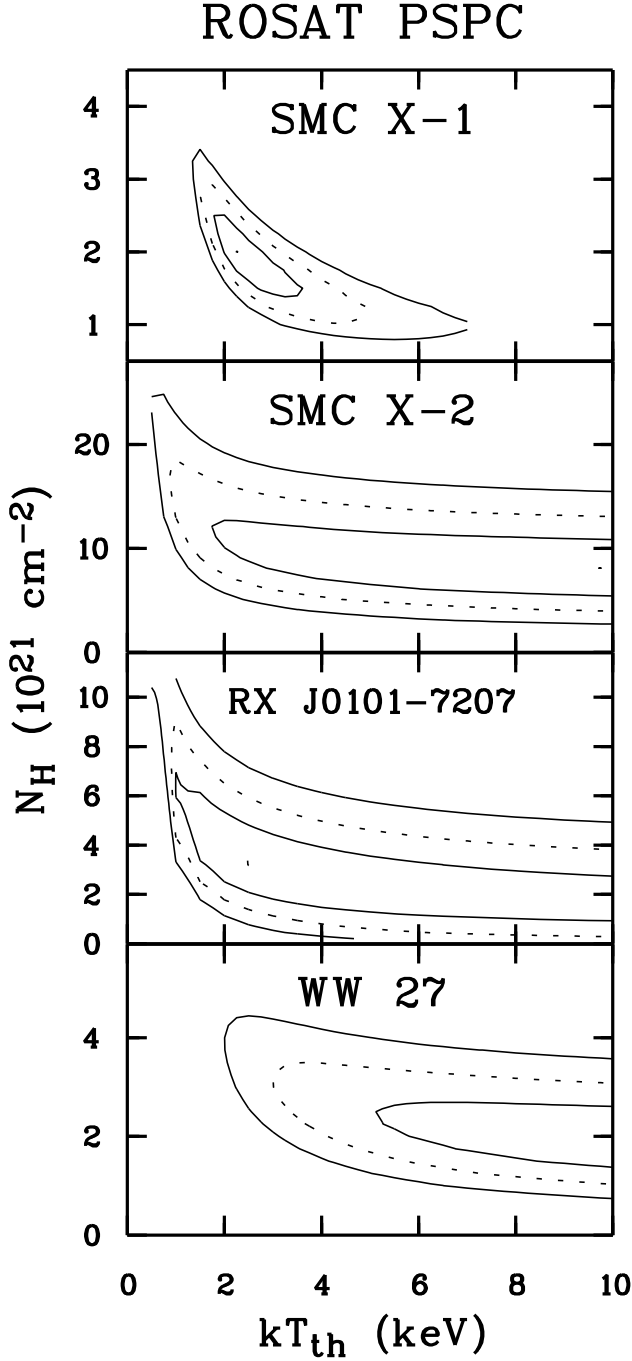
ROSAT PSPC

Fig. 5. 68, 95, and 99% confidence parameter plane for the hydrogen absorbing column density within the SMC (assuming SMC metal abundances reduced by a factor of ~ 7 compared to galactic opacities) with a galactic absorption term of $3 \times 10^{20} \mathrm{cm}^{-2}$ and the temperature of a thermal bremsstrahlung fit applied to the spectra of the four X-ray binaries SMC X-1, SMCX 2, RX J0101.0-7206 and RX J0051.8-7231 (WW27) (from top to bottom).

Table 7. Hydrogen column densities for the spectrally soft and hard candidate X-ray binaries as deduced from a spectral fit assuming blackbody flux distributions for the supersoft sources and thermal bremsstrahlung distributions for the hard sources. The values for the hard sources have been taken from Table 6 and for the supersoft sources from Kahabka et al. (1994). For comparison hydrogen column densities, deduced from 21-cm radio data (HI columns) are given. The latter values have been deduced from a HI map reproduced from Luks (1994) and smoothed with a Gaussian σ of $8'$.

Cat. num.	Source name	Hydrogen column $[10^{21} \ cm^{-2}]$	
		spectral fit	21-cm (HI)
	hard X-ray sources		
242	SMC X-1	2.38(-0.9,+0.98)	2.89
100	SMC X-2	5.70(-1.7,+12)	2.54
3	RX J0032.9-7348	5.3(-4,+8)	0.3
69	RX J0049.1-7250	33	4.73
83	RX J0051.8-7231	1.87(-1.1,+2.6)	2.79
84	RX J0052.1-7319	7.1	5.14
158	RX J0101.0-7206	2.46(-2)	2.98
	supersoft sources		
20	1E 0035.4-7230	0.5(-0.15,+0.3)	0.3
135	1E 0056.8-7146	0.77(-0.2,+0.8)	1.54
62	RX J0048.4-7332	5.8(-4.4,+1.1)	4.22
133	RX J0058.6-7146	0.28(-0.28,+6)	1.93

Table 8. *ROSAT* all-sky survey 2σ upper limit count rates (0.1-2.4 keV), observation intervals, and exposure times of the 9 candidate X-ray binaries in the SMC (cf. Table 3) not detected in the all-sky survey observations.

| Source name	2σ rate $[10^{-3}/s]$	time [UT 1990] start - end	expos. [sec]
SMC X-2	7.0	21 Oct 22:13 - 26 Oct 11:06	780
SMC X-3	9.7	24 Oct 14:17 - 28 Oct 11:09	638
RX J0032.9-7348	6.8	20 Oct 14:10 - 24 Oct 31:40	640
RX J0049.1-7250	5.9	24 Oct 07:53 - 28 Oct 07:56	722
RX J0051.8-7231	11.1	22 Oct 19:02 - 26 Oct 14:19	667
RX J0052.1-7319	8.4	24 Oct 07:53 - 27 Oct 12:44	783
RX J0059.2-7138	14.1	27 Oct 06:19 - 31 Oct 04:48	501
RX J0101.0-7206	19.1	26 Oct 06:18 - 30 Oct 07:59	530

ROSAT PSPC
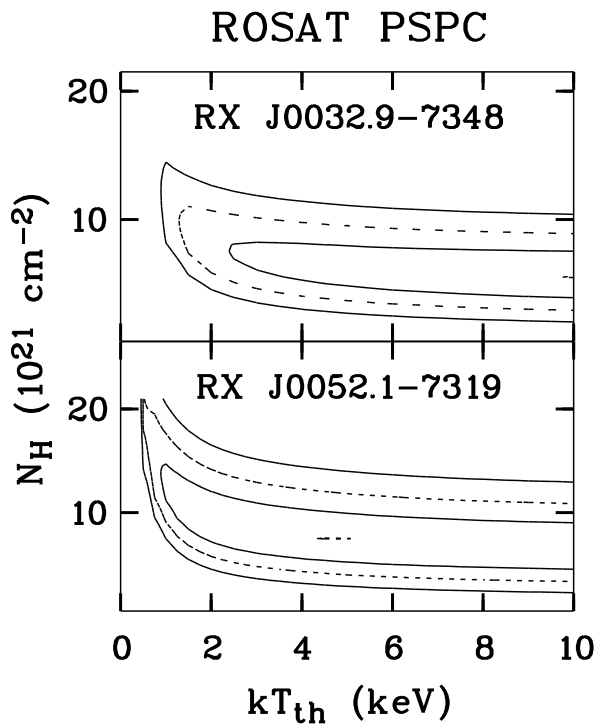
Fig. 6. As in Fig.5, but for the two candidate X-ray binaries RX J0032.9-7348 and RX J0052.1-7319.

ration flare is a factor of 10 and the peak luminosity in the flares is $\sim 7 \times 10^{37}$ erg s^{-1}. This luminosity is deduced for a distance of 65 kpc. The true luminosity may be a factor of 2 lower, as from optical data a distance of $\sim$45 kpc is favored (Howarth 1982). This is consistent with SMC X-1 being located in a spiral arm extending from the bulge of the SMC towards our Galaxy (cf. Gardiner et al. 1994). The spectrum of SMC X-1 is soft with a thermal bremsstrahlung temperature close to 2 keV (cf. Figure 5). The X-ray eclipse of SMC X-1 has been found from COS-B data (2-12 keV) to have a duration of 0.65 days (cf. Bonnet-Bidaud & an der Klis 1981). But in the *ROSAT* data we see an extended and shallow eclipse with residual flux of $\sim$ 0.1 counts s^{-1} in the minimum. This may be explained by the fact, that the optical star appears bigger in the soft X-ray band due to the stellar wind driven from its surface.

Bonnet-Bidaud & van der Klis (1981) observed from COS-B data extending over an observation period of 38 days the transition from a low to a high intensity state (a turn-on). They come to the conclusion, that the high-state luminosity cannot be explained by wind accretion and propose Roche lobe overflow as origin. They propose quasi-periodic changes in the mass loss rate from Sk 160 e.g. due to g-modes (Papalaizou 1979) to be responsible for the switch over from low-intensity to high intensity

states. The fact that SMC X-1 was in a total of nine observations performed by *HEXE* (20-50 keV) only 4 times detectable - above a 5σ level - (Kunz et al. 1993), indicates that the low-states are not highly absorbed states of the X-ray source but more probably real changes in the accretion rate mediated by an accretion disk to the NS. This is supported by the recently published 7 year light curve of SMC X-1 generated from Vela 5B data (Whitlock & Lochner 1994) in which the source only once has been found for about 100 days in a high intensity state.

SMC X-1 has been observed by *ROSAT* (from 6-Oct-91 4:02 UT till 8-Oct-91 3:05 UT) in a high-intensity state. This gives the unique opportunity to study SMC X-1 in two low-states separated by quite exactly 1 year and in one high-state which was observed shortly (only $\sim$7 days) before the second low-state. We therefore can study one transition in states (turn-off) in a similar way as has been possible for Bonnet-Bidaud & van der Klis (1981) (with COS-B data) during a turn-on at higher energies (2-12 keV). We generated the orbital light curve for the *ROSAT* high-state observation and show the result together with the (16-19) October 91 low-state observation in Figure 8.

There is a clear spectral change observed with the source being much harder during the high-state indicating that the direct accretion luminosity from the NS is observed. This is supported by the fact, that X-ray pulsations have been discovered. The results of a detailed analysis of this high-state observation is presented in Blondin & Woo (1995) and Woo et al. (1995). As the high-state observation covers only the phase region $\sim$ 0.5 − 0.7 of the binary orbit, only a quite incomplete comparison is possible. The intensity in the high-state is a factor of $\sim$6 higher than in the two low-state flares.

3.4.2. The Be type transient SMC X-2

SMC X-2 (2S 0052-739) is a transient X-ray source discovered by *SAS-3* 1977 October 11 to 16 (Clark et al. 1978). The X-ray luminosity (2-11 keV) was deduced as 8.4×10^{37} D$_{65}^2$ erg/s, where D$_{65}$ is the distance in units of 65 kpc. In a follow-up observation 1 month later the source was no longer detected. The 3σ upper limit of the luminosity was 8.4×10^{36} D$_{65}^2$ erg/s (Clark et al. 1979). This shows, that SMC X-2 varies at least by a factor of 10 on a time scale of 1 month. It has not been detected a second time before *ROSAT* . An optical counterpart (within the 20" error circle) proposed by Sanduleak & Phillips (1977), has been studied by Allen (1977), van Paradijs (1977), Crampton et al. (1978), Murdin et al. (1979). The optical counterpart was resolved into two components of spectral type O7$\pm$2(V = 15.2) and B1$\pm$2e(V = 16.0) by Murdin et al. (1979). The association of X-ray sources with Be stars (Maraschi et al. 1976) led Murdin et al. (1979) propose the weaker component to be the more likely optical counterpart of SMC X-2. Tarenghi et al. (1981) obtained a far UV spectrum of SMC X-2 with the International Ultra-
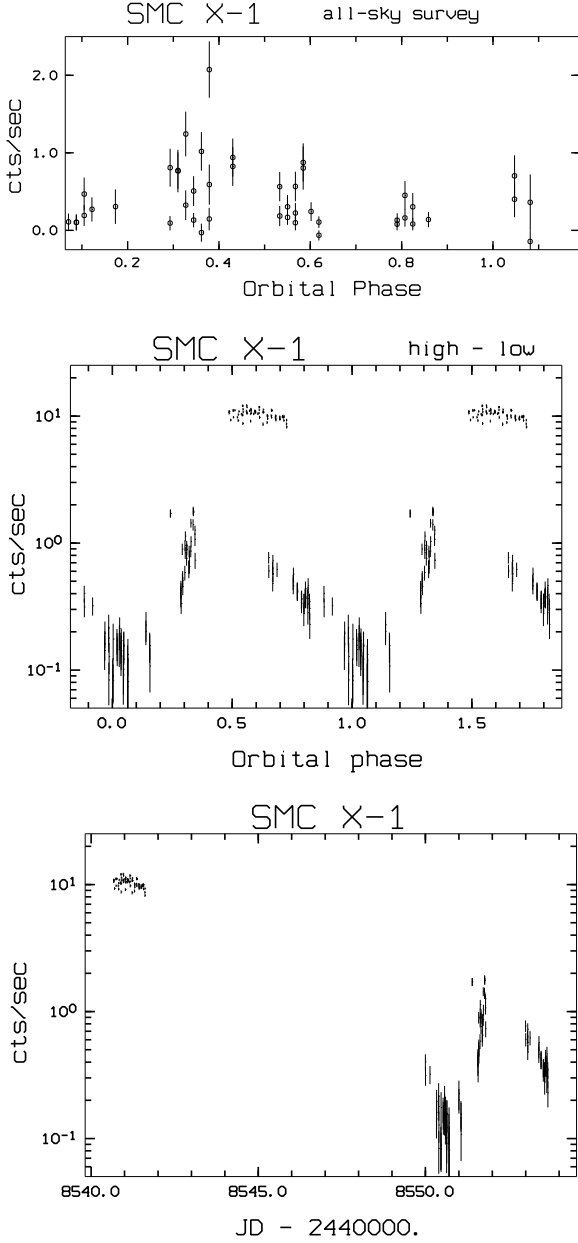
Fig. 8. First panel: Binary orbit light curve (0.5-2.4 keV) of SMC X-1 as observed during the RASS. One data point is an integration of 20 sec. An orbital period of 3.89229188 days and an epoch for the mid eclipse center JD 2447740.85906 has been chosen (cf. Levine et al. 1993). Second panel: Binary orbit light curve (0.5-2.4 keV) of SMC X-1 during a high and a low-intensity state. The high-state light curve is poorly sampled. Two cycles of the binary orbit are repeated. Third panel: Same data plotted as a function of time (Julian Date JD is given). The high-state precedes the low-state by about 7 days.

violet Explorer (*IUE*). They come to the conclusion that the O7 star dominates the UV spectrum and not the B1e star. The question remains open which component is the optical counterpart.

ROSAT captured SMC X-2 during another X-ray outburst 14 years after the first observed outburst in (1977). The observation lasted only for 1350 seconds. The source had a luminosity of 2.7×10^{37} erg s^{-1} (0.15-2.4 keV) taking into account a column density of 2.9×10^{21} atoms cm^{-2} and a thermal bremsstrahlung temperature of 10 keV from the spectral fit. The value for the absorption has been deduced by assuming a galactic contribution of 3×10^{20} cm^{-2} and a SMC intrinsic contribution of 2.1×10^{21} cm^{-2} with metals reduced by a factor of ~ 7. The luminosity observed with *ROSAT* (0.15-2.4 keV) is a factor of 3 smaller than the luminosity observed by *SAS 3* (2-11 keV). The difference in energy band cannot account for this difference as *ROSAT* may have seen the higher luminosity part of the spectrum. Since neither the *ROSAT* nor the *SAS 3* observation covered the rise and decay of the outburst it is not clear, if the luminosity difference reflects a difference in the peak luminosities of the two observed outbursts.

3.4.3. The binary candidate RX J0051.8-7231

The earlier *Einstein* error box of RX J0051.8-7231 of 40″ radius (source #27 in the *Einstein* catalog of Wang & Wu 1992) coincides with the bright SMC B1 star AV 111 (Bruhweiler 1987, Wang & Wu 1992). But within the smaller error circle deduced from the *ROSAT* observations with a radius of 11″ a blue emission line star has been found, which is a likely optical candidate (Pakull, private communication). The source flux increased by a factor > 10 over a period of ~ 1 year and by a factor of ~ 5 in 5 days with a significant variation in the hardness ratio. The moderate X-ray luminosity ($10^{35} - 10^{38}$ erg s^{-1}), the large flux variation, the relatively hard spectrum and the early-type star counterpart suggested a Be type origin of the X-ray source. Recently Israel et al. (1995) reported about the discovery of 8.9 s pulsations in *ROSAT* data of this source (in pointing E, cf. Table 1). This finding makes the source a firm X-ray binary in the SMC. An orbital period has not yet been determined.

From *ROSAT* observations we confirm RX J0051.8-7231 (WW 27) to be variable by a factor >10. During a pointing covering 3 days the source showed a nearly linear increase in luminosity ranging from $\sim 2 \times 10^{36}$ erg s^{-1} to $\sim 6 \times 10^{36}$ erg s^{-1} deduced from a spectral fit with a SMC intrinsic absorption of 2×10^{21} atoms cm^{-2} (cf. Figure 3). In two other pointings the luminosity was $\le 1.1 \times 10^{35}$ erg s^{-1} (cf. Table 3 and Table 5). This behavior is characteristic for HMXBs with luminosities below 10^{37} erg s^{-1} showing erratic flaring activity (cf. White 1989).

3.4.4. The binary candidate RX J0052.1-7319

RX J0052.1-7319 has already been discovered in *Einstein* observations (source #29 in the catalog of Wang & Wu (1992) and #8 in the catalog of Inoue, Koyama & Tanaka (1983)). It correlates with the nebular complex DEM 70 (Davis, Elliot & Meaburn 1976). The source has not been considered as an X-ray binary candidate from *Einstein* observations. *ROSAT* detects this source to be variable by a factor of ~ 4 in an observation (B2) covering 5 days (cf. Figure 4). The X-ray luminosity varies from 6×10^{35}erg s^{-1} to 2.6×10^{36}erg s^{-1} deduced from a spectral fit with a SMC intrinsic absorption of 7×10^{21}cm^{-2}. An optical counterpart has not been found for this source. Kahabka (1995a) gives a correlation with a B star for this source. But this is in error.

Table 9. *Einstein* and *ROSAT* names of those X-ray binary sources, which have been found during *Einstein* and *ROSAT* observations. The *Einstein* name is adopted or deduced (from the catalogued coordinates) from the information given in Wang & Wu (1992). For the two supersoft sources 1E 0035.4-7230 and 1E 0056.8-7146 we did not introduce a new *ROSAT* name, as these sources have been optically identified before the *ROSAT* observations.

Einstein name	*ROSAT* name
1E 0035.4-7230	–
1E 0050.1-7247	RX J0051.8-7231
1E 0050.3-7335	RX J0052.1-7319
1E 0056.8-7146	–

3.4.5. Discovery of a new transient RX J0101.0-7206

RX J0101.0-7206 has been discovered by *ROSAT* in pointing A1 at a luminosity of 1.3×10^{36}erg s^{-1}. About half a year later the X-ray source has disappeared with a 2σ upper limit X-ray luminosity (assuming that the spectral parameters did not change) of 4.6×10^{34} erg s^{-1} (cf. Table 3 and Table 5). The source has not been detected in *Einstein* observations. This suggests a transient nature. The source most probably is associated with a 15-16'th magnitude Be star (Pakull, private communication). RX J0101.0-7206 lies at the north-eastern boundary of the star formation region N66. A few additional but persistent X-ray sources have been detected by *Einstein* and confirmed with *ROSAT* clustering around N66 (Kahabka et al. 1996). They have been interpreted as SNRs (Ye et al. 1991).

3.4.6. RX J0049.1-7250, an AGN or X-ray binary

RX J0049.1-7250 has been discovered with *ROSAT* in pointing B1. It is extremely absorbed with $\sim$1-3×10^{22}atoms cm^{-2} (cf. Table 6) and most probably lies at the far side of the SMC seen through the bulge (with a total HI column of $\sim 5.5 \times 10^{21}$ cm^{-2}, cf. Figure 7). The best-fit thermal bremsstrahlung temperature of 1 keV gives a luminosity of 2.5×10^{37}erg s^{-1} for using galactic absorbing opacities. A luminosity above 10^{38}erg s^{-1} is deduced for SMC opacities. But the uncertainty in the column density determination is probably too high to assume that the source was in a super-Eddington bright state. Half a year later the luminosity has decreased by a factor of 10 or more with the absorption not markedly changed. This confirms the source to be behind the SMC probably seen during and after a flare. We cannot at the moment exclude that RX J0049.1-7250 is a time variable AGN shining through the SMC. If the source is a SMC X-ray binary then it could be located in the far-off spiral arm (wing) of the SMC (see the simulation of the Magellanic system by Gardiner et al. 1994). In the bright state it would show a similar X-ray luminosity as SMC X-1, which is supposed to lie in the spiral arm pointing towards our Galaxy.

3.4.7. RX J0032.9-7348

This source lies at the south eastern boundary of the body of the SMC. It is only contained in pointings F1 and F2. The source is variable by a factor of ~ 6 over a time of ~ 0.4 years. In the X-ray bright state (pointing F2) a spectral fit could be applied. An absorbing hydrogen column of 2.5×10^{21} atoms cm^{-2} and 5.3×10^{20} atom cm^{-2} is obtained in a thermal bremsstrahlung and in a blackbody description respectively. A temperature of > 1 keV and 0.6 keV is obtained. The unabsorbed bolometric blackbody luminosity would be 2.5×10^{36} erg s^{-1} and the thermal bremsstrahlung luminosity (0.1-2.4 keV) 2.6×10^{36} erg s^{-1} for a distance of 65 kpc (SMC membership). Assuming that the source spectrum did not change from pointing F1 to F2, an (unabsorbed) luminosity of 3×10^{35} erg s^{-1} is deduced for the X-ray faint state. A 15.3 mag blue object, GSC 0914101338 is 22″ from the X-ray position and may be a good candidate (Pakull, privte communication). The star HV 1328 has been found in the *Strasbourg catalog* at a distance of 67″ from the source. This is about the positional uncertainty at the large off-axis angle (43′) where the source has been found. As the X-ray spectrum cannot be explained by coronal emission and as the duration of the X-ray bright state is ~ 5 days (cf. Figure 4) a flare star nature may be excluded. These facts are in favor for a SMC membership of the source. The hard spectral characteristic is in favor for a HMXB nature of the source.

3.4.8. SMC X-3

SMC X-3 (2S 0050-727) has been discovered with *SAS 3* at a luminosity (2-11 keV) of 5.9×10^{37} D_{65}^2 erg/s (Clark et al. 1978). It is a transient source probably of the Be type. In a follow-up observation 1 month later the source was no longer detected (the 3σ upper limit for the luminosity is 8.3×10^{36} D_{65}^2 erg/s). The source varies at least by a factor of 7 within 1 month (Clark et al. 1979). No second detection of the source has been reported up to now.

SMC X-3 has been in the field of view of the pointings A1, A2 and E (cf. Table 5). It has not been detected in these observations. The upper limit to the count rates (cf. Table 5) indicates to the very low luminosity (below $\sim 3.5 - 10 \times 10^{34}$ erg s^{-1}, assuming a SMC X-2 like spectrum) during these periods. This is in agreement with the Be type transient identification of SMC X-3. We also refer to the paper of Pietsch et al. (1986), where an upper limit luminosity of 2×10^{33} erg s^{-1} (2-6 keV) has been deduced for the Be type transient GX 304-1 from *EXOSAT* observations around the time of an expected periodic outburst. It has been argued, that the shell of the Be system has diminished in this system.

3.4.9. The 2.8 s transient RX J0059.2-7138

This transient has been discovered by Hughes (1994) as a serendipitous source in a pointed observation on 12 May 1993 towards the bright supernova remnant SNR 0102-72.2 in the SMC. The transient was very bright (7.8 cts counts s^{-1}) and showed a pulsed signal of 2.76 s. The source is probably correlated with a blue $B_j \sim$ 14.1 mag HST guide star. As the source has not been seen in previous observations of the SMC (neither *Einstein* nor *ROSAT*) Hughes concluded the source is probably a Be type transient. We add in our analysis further pointed observations towards the direction of this pulsar, however did not detect the source in an observation 44 days before the reported outburst nor 142 days afterwards. This limits the maximum outburst duration to less than 6 months. Upper limits for the source are more than a factor of 1000 below the outburst luminosity (cf. Table 5).

3.4.10. H 0107-750

H 0107-750 (1H 0103-762) has been seen with the *HEAO A1* (Wood et al. 1984) and *HEAO A3* (Tuohy et al. 1988) experiment. Whitlock & Lochner (1994) found in *Vela 5B* data mapping the region of the source for 7 years three outbursts with luminosities of $\sim 4 \times 10^{38}$, $\sim 4 \times 10^{38}$ and $\sim 6 \times 10^{38}$ erg s^{-1} in the 3-12 keV energy band. The outburst occurred in 1969 July, 1969 October and 1970 February. The outburst lasted for ~ 35 days.

The position of H 0107-750 is not covered by any of our pointed *ROSAT* observations. The source has not been detected during the RASS (cf. Kahabka & Pietsch 1993).

4. Discussion

4.1. Transient and persistent sources

It is of interest to compare the number of persistent with the number of transient X-ray binary candidates. A source is considered to be a transient, if it is in the field of view of at least two observations and below the detection limit of at least one observation. From Table 5 it becomes clear that four of the spectrally hard sources, e.g. SMC X-2, RX J0101.0-7206, SMC X-3, RX J0059.2-7138 fall into this category. They have not been detected in least one pointing with a 2σ upper limit count rate in the 0.5-2.4 keV band of $< 7. \times 10^{-4}$ counts s^{-1}. This corresponds to a luminosity below $\sim 2. \times 10^{34}$ erg s^{-1}. They all are (or may be) Be type transients. Two sources, RX J0051.8-7231 and RX J0052.1-7319, have not been detected at least once. But both sources are known from *Einstein* observations and we classify them as persistent and variable. RX J0049.1-7250 and RX J0032.9-7348 are also considered as persistent and highly variable. This gives, including SMC X-1, 5 persistent (and variable) and 4 transient hard X-ray binary candidates.

The supersoft X-ray binary sample (with a much smaller number of objects) gives two persistent sources (1E 0035.4-7230 and 1E 0056.8-7146) and two transient sources (RX J0048.4-7332 and RX J0058.6-7146). In the supersoft sources, which are in a steady-state nuclear burning condition, variability in the X-ray flux (by a factor in excess of $\lesssim 3$) is not predicted to occur (cf. Fujimoto 1982). The recurrently burning systems (cf. Fujimoto 1982, Kahabka 1995b) show variability. Variability in the X-ray flux related to the binary orbit is also observed in a few systems (like 1E 0035.4-7230, cf. Kahabka 1996).

In our Galaxy the existence of ~ 40 HMXB systems (with evolved companions) and of $(2-6) \times 10^3$ Be type X-ray binaries has been estimated by van Paradijs & Mc-Clintock (1995). This clearly shows that the Be type transients outnumber the persistent and variable sources by a substantial number and ever more transients are expected to be discovered in future observations (there may be presently ~ 300 Be type transients in the SMC, cf. Kahabka 1995a).

A mechanism for transient behavior different from that of the Be star phenomenon has been proposed by Stella, White & Rosner (1986), centrifugal inhibition of accretion (see also Waters and van Kerkwijk 1989). Stella et al. (1989) have shown, that a fair fraction of the NSs in transient X-ray binaries containing OB supergiant secondaries rotate close to the critical equilibrium rate at which the corotation radius equals the magnetospheric radius. A moderate increase in the mass accretion rate can turn these sources (during outburst) into very luminous transients. Otherwise these sources may be dormant. For a magnetic dipole moment of $\sim 10^{30}$ Gauss cm^{-3} and (maximum) X-ray luminosities of $\sim 10^{36} - 10^{38}$ erg s^{-1} NS ro-

tation periods of $\sim$0.7-50 s are predicted if the system is close to centrifugal inhibition. For typical wind parameters of supergiant and Be X-ray binaries orbital periods of $\sim$1-40 days are expected. SMX X-1 falls well into this regime. Probably part of the X-ray variability we observe in the persistent sources may be related to this phenomenon.

4.2. The luminosity distribution

For the seven hard X-ray (binary) sources in the SMC a number-luminosity diagram has been generated. The values for the luminosity (0.15 - 2.4 keV) were taken from Table 6. SMC X-1 was observed in a low luminosity state (cf. Marshall et al. 1983), RX J0059.2-7138 has not been included in the diagram as the high (bolometric) luminosity reported for the soft component is based on a blackbody fit and may be doubted or is at least highly uncertain. SMC X-3 has not been seen with *ROSAT* and has not been included either. The transient X-ray sources have luminosities (0.15-2.4 keV) ranging from 5×10^{35}erg s^{-1} to $\sim 10^{38}$erg s^{-1} (cf. Figure 9). These luminosities are considerably lower than the super-Eddington luminosities inferred for SMC X-1, SMC X-2 and SMC X-3 (Clark et al. 1978). But one has to note, that with *ROSAT* SMC X-1 has been found during a high-state in a super-Eddington bright state (Woo et al. 1995) and for the new discovered SMC transient RX J0059.2-7238 a supersoft component with bolometric super-Eddington luminosities has been measured (Hughes 1994). This is in favor for the luminosity distribution of the SMC HMXBs extending to large values, probably to larger values as is found in the galactic supergiant and Be type X-ray binaries (cf. van Paradijs & McClintock 1995). In the 1970's, when the very luminous MC X-ray sources were discovered, the reduced metallicities of the Clouds have been considered as a possible link to a luminosity increase. X-ray heating (of a not fully ionized gas) depends due to photoabsorption strongly on the atomic number Z (cross-section for photoabsorption $\sigma_{\rm ph} \propto Z^4$). A lower Z gas is less affected by heating and higher accretion luminosities can be reached in agreement with the observation of higher luminosity sources in the MCs (cf. discussion in van Paradijs & McClintock 1995). Obviously we now observe with *ROSAT* in addition to these super-Eddington bright sources (due to the increased sensitivity) the lower-luminosity distribution. One can now ask the question whether the whole luminosity distribution of the MC HMXBs is just shifted to larger luminosities or extends over a broader range. This question cannot be answered yet. But the observations indicate, that the outburst luminosities of the (identified and classified) MC Be-type X-ray binaries are well above 10^{35} erg s^{-1}, the lower limit found for the galactic pendants (Figure 2 of van Paradijs & McClintock 1995).
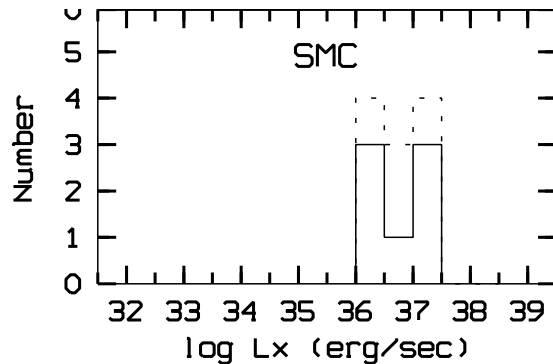

Fig. 9. Number-luminosity diagram of the SMC X-ray binaries with luminosities in the energy range 0.15-2.4 keV. The solid line gives the distribution of the hard X-ray binaries and the dotted line the distribution with the supersoft sources added.

4.3. Extrapolation from the SMC to the Galaxy

With the SMC we have due to its closeness to the Galaxy the unique opportunity to study stellar populations outside of our Galaxy. With the deep *ROSAT* pointings we covered a large fraction of this galaxy rather homogeneously. Using a point source detection procedure and applying selection criteria for a candidate sample of X-ray binaries we were able to set up a rather firm sample with an intrinsic source luminosity above 3×10^{35} erg s^{-1}. This gives in total 10 persistent and transient hard X-ray binaries and 4 supersoft binaries. Scaling with the mass ratio between the SMC and the Galaxy of $\frac{1}{60}$ (McGee & Hindman 1971) $\sim$400 hard X-ray binaries and $\sim$250 supersoft X-ray binaries would be expected to be seen in the Galaxy in case the star formation rate in the SMC and in our own Galaxy were similar (cf. for a discussion Clark et al. 1978, see also introduction). As the metallicity of the SMC is strongly reduced one can assume that there are not many hidden sources and this extrapolation is close to the total number of active hard and supersoft sources. The number of 250 SSS would be reasonably close to the number of $\sim$1000 expected galactic supersoft sources (Rappaport et al. 1994). van den Heuvel et al. (1992) estimated the number of HMXBs in the Galaxy containing a NS to $\sim 10^4$. Obviously only a small fraction of them is active with luminosities above a few 10^{35} erg s^{-1}. The total number of known (steady and transient) X-ray sources in the Galaxy is $\lesssim$100 (van Paradijs 1995). The latter discrepancy could be explained by a better sampling of the SMC compared to the Galaxy.

4.4. The nature of the rejected X-ray binary candidates

Certainly our selection criteria for X-ray binaries are not giving a firm sample of candidates. Nor can we be sure, that any of the rejected candidates (cf. Table 3) will not

turn out to be an X-ray binary in the SMC. This decision may only be secure, after an optical identification of the objects in debate has been achieved. The X-ray nature of the sources not discussed in this paper will be the subject of a forthcoming paper. A first spectral and timing analysis of the rejected candidates listed in Table 2 with off-axis angles $< 30'$ has been performed. Only the source RX J0100.7-7206 has the spectral appearance of a background AGN, e.g. a large SMC intrinsic hydrogen column (assuming metallicities reduced by a factor of ~ 7) of 3.1×10^{21} cm^{-2} and a powerlaw photon index of -2.3 (cf. Figure 10). The value of the hydrogen column is consistent with the total SMC HI column in this direction deduced from 21-cm data (Luks 1994, cf. Figure 7). A flux (in the 0.1-2.4 keV band) of 3.12×10^{-13} erg cm^{-2} s^{-1} is deduced. It may be interesting to note that Ye & Turtle (1993) found in their 843 MHz radio survey of the SMC no significant difference in the number of background sources (e.g. AGNs) compared to regions distant from the Clouds and at high Galactic latitudes.

For the other two sources RX J0054.9-7226 and RX J0055.4-7210 low SMC intrinsic hydrogen column densities of 2.7×10^{20} and 1.3×10^{21} cm^{-2} have been found and power law indices of -0.2 and -2.1. Taking into account the uncertainties in the deduced parameters then RX J0055.4-7210 may still be compatible with an AGN. The low absorbing hydrogen column found for RX J0054.9-7226 would indicate either a galactic foreground or a SMC object at the near side of the SMC.
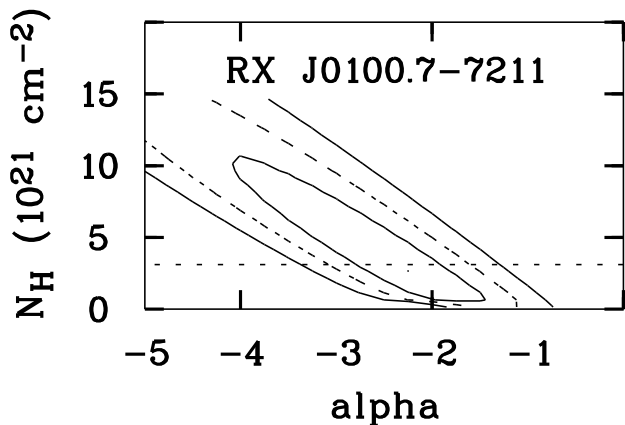

Fig. 10. 68, 95, and 99% confidence parameter plane for the powerlaw photon index versus the hydrogen absorbing column density within the SMC (assuming metal abundances reduced by a factor of ~ 7 compared to galactic abundances) for the possible background AGN RX J0100.7-7211, shining through the SMC bulge with a total SMC hydrogen column of 3.1×10^{21} cm^{-2} (dashed line, cf. Luks 1994 and Figure 7).

5. Summary

A systematic search for spectrally hard and soft X-ray binary systems in the SMC has been performed in the *ROSAT PSPC* pointed data towards this galaxy. A selection has been applied to a list of X-ray sources to find candidate X-ray binaries. Detectable time variability and spectral properties determined from hardness ratio arguments were used as the criteria. The luminosity threshold was $\sim 3 \times 10^{35}$ erg s^{-1} mainly depending on the assumed absorbing column density towards the source. A catalog search for optical candidates coinciding with the error circle of the X-ray source has been performed and used as an identification criterion. From a list of 15 candidate hard X-ray binaries and 5 candidate soft X-ray binaries 7 and 4 respectively were finally selected after taking into account other information like correlation with a SMC O or B star. A few selected sources can still be (time variable) background AGNs which have a chance superposition with the SMC. The supersoft sample has been discussed in Kahabka et al. (1994). The most prominent X-ray source is SMC X-1. It was until recently the only SMC X-ray binary for which an orbital period has been determined. This situation changed, when a 4.$^{\rm h}$1 orbital period has been discovered in the optical data of the supersoft SMC source 1E 0035.4-7230 (Schmidtke et al. 1994). SMC X-1 is also one of the few (2) SMC NS X-ray binaries for which the rotation period of the NS has been determined (besides RX J0059.2-7138 and RX J0051.8-7231). SMC X-1 is known to show low and high intensity states as is observed in many HMXBs. *ROSAT* pointed observations covering a full binary cycle of ~ 4 days depicted the source in a low state. Two short X-ray flares reaching peak luminosities close to 10^{38} erg s^{-1} and one long duration flare were recorded. The low-state spectrum has been found to be softer than the reported high-state spectrum. SMC X-2 is a Be type transient discovered already 14 years before the *ROSAT* observations but has only been seen once in outburst. A second outburst has been detected by *ROSAT* during a very short pointing. The soft X-ray spectrum of the source has been measured for the first time. A large absorbing column has been found. RX J0051.8-7231, a possible HMXB, has been discovered in *Einstein* observations as a variable source and has been extensively studied with *ROSAT* . RX J0101.0-7206 has been discovered during an X-ray outburst at the north-eastern boundary of the giant SMC HII region N66 with a luminosity of $\sim 10^{36}$ erg s^{-1}. RX J0049.1-7250 has been discovered with *ROSAT* . It is located north-east of the SMC supernova remnant N 19. It shows high absorption which indicates that the source is behind the SMC and has been detected with most probably a luminosity at the Eddington limit during the X-ray bright state. No optical counterpart has been found. The luminosity distribution deduced for the SMC X-ray binaries matches within the small number of the objects considered the distribution of galactic bulge sources. Scaling

Table 10. Spectrally hard and supersoft X-ray binaries (and candidate X-ray binaries) in the SMC. The following information is given: The name of the source, the *ROSAT PSPC* count rate, the temperature of the soft blackbody component (given also for the hard binaries in case an additional soft component has been detected or has been known before), the temperature of the hard thermal bremsstrahlung component, the optical counterpart, the visual optical magnitude, the orbital period, the spectral type of the optical counterpart, remarks and references.

Name	PSPC [c/s]	kT soft [ev]	hard [keV]	variab.	opt. ID	m_v	type	orb.Per. [d]	remarks	Ref.[a]
Hard X-ray Binaries (& candidates)
SMC X-1	0.37	- 160	$1.8^{-0.7}_{+2.7}$	flares persist.	Sk 160	13.2	B0I	3.89	low-state high-state	1-20
SMC X-2	0.39	-	10^{-9}_{+0}	trans.	+	15.2/ 16.0	O7 ± 2/ B1 ± 2e	-	rediscovered	21-30
SMC X-3	-						O9(III − V)e			22-23
RXJ0032.9-7348	0.12	-	10^{-9}_{+0}	variab.	?	-		-	candidate	
RXJ0049.1-7250	0.048	-	1-8	variab.	-	-		-	candidate	21
RXJ0051.8-7231	0.11	-	10^{-8}_{+0}	variab.	?	-		-		21,31-32,42
RXJ0052.1-7319	0.021	-	1-17	variab.	-	-	-	-	candidate	21
RXJ0059.2-7138	7.8	35	?	trans.		14.1	blue	-	candidate	41
RXJ0101.0-7206	0.048	-	$3.5^{-3.5}_{+6.5}$	trans.	-	-	-	-	candidate	21
H0107-750				variab.	-	-	Be	-	candidate	40
Supersoft X-ray Binaries (& candidates)
1E 0035.4-7230	0.38	41	-	variab.	+	20.2		0.17		31,33-35
1E 0056.8-7146	0.33	28	-		N67	16.6	PN	-		33,37-39
RXJ0048.4-7332	0.19	20	-		SMC3	15.5	symb.nova	-		33,36
RXJ0058.6-7146	0.025	42	-	outburst	-	-		-		33

[a] Ref.:
(1) Angelini, Stella & White, 1991; (2) Bonnet-Bidaud & van der Klis, 1981; (3) Bonnet-Bidaud, et al., 1981; (4) Bunner & Sanders, 1979; (5) Darbro, 1981; (6) Davison, 1977; (7) Hammerschlag-Hensberge, et al., 1984; (8) Henry & Schreier, 1977; (9) Howarth, 1982; (10) Hutchings & Crampton, 1977; (11) Kunz et al., 1993; (12) Levine, et al., 1993; (13) Marshall, White & Becker, 1983; (14) Osmer & Hiltner, 1974; (15) Primini, Rappaport & Joss, 1977; (16) Reynolds, et al., 1993; (17) van Genderen, 1974; (18) van Genderen & van Groningen, 1981; (19) van der Klis, et al., 1982; (20) Wilson & Wilson, 1976; (21) Kahabka 1995; (22) Clark et al. 1978; (23) Clark et al. 1979; (24) Sanduleak & Philips 1977; (25) Allen 1977; (26) van Paradijs 1977; (27) Crampton et al. 1978; (28) Murdin et al. 1979; (29) Maraschi et al. 1976; (30) Tarenghi et al. 1981; (31) Wang & Wu 1992; (32) Bruhweiler 1987; (33) Kahabka et al. 1994; (34) Orio et al. 1994; (35) Schmidtke et al. 1994; (36) Vogel & Morgan 1994; (37) Wang 1991; (38) Wang & Wu 1992; (39) Heise et al. 1994; (40) Whitlock & Lochner 1994; (41) Hughes, 1994; (42) Israel et al. 1995.

with the mass ratio between the SMC and our Galaxy of $\frac{1}{60}$ (McGee & Hindman 1971) ~400 hard X-ray binaries and ~250 supersoft X-ray binaries would be expected to be seen in our Galaxy in case the star formation rate in the SMC and in our Galaxy is similar (cf. for a discussion Clark et al. 1978). As the metallicity of the SMC is strongly reduced one can assume that there are not many hidden sources and this extrapolation is close to the total number of active hard and supersoft X-ray sources. The number of 250 supersoft sources would be reasonably close to the number of ~1000 expected galactic supersoft sources (Rappaport et al. 1994). van den Heuvel (1992) estimated the number of HMXBs in the Galaxy contain-ing a NS to ~ 10^4. Obviously only a small fraction of them is active with luminosities above a few 10^{35} erg s^{-1}.

References

Allen D., 1977, IAU Circ. No. 3143

Angelini L., Stella L., White N.E., 1991, ApJ 371, 332

Balucinsca-Church M., McCammon D., 1992, ApJ 400, 699

Bessell M.S., 1991, A&A 242, L17

Blondin J.M., Woo J.W., 1995, ApJ 445, 889

Bonnet-Bidaud J.M., van der Klis M., 1981, A&A 97, 134

Bonnet-Bidaud J.M., Ilovaisky S.A., Mouchet M., et al., 1981, A&A 101, 184

Bruhweiler F.C., Klinglesmith III., Gull T.R., et al., 1987, ApJ 317, 152

Bunner A.N., Sanders W.T., 1979, ApJ 228, L19

Caldwell J.A.R., Coulson I.M., 1986, MNRAS 218, 223

Clark G., Doxsey R., Li F., et al., 1978, ApJ 221, L37

Clark G., Li F, van Paradijs J., 1979, ApJ 227, 54

Crampton D., Hutchings J.B., Cowley A.P., 1978, ApJ 223, L79

Darbro W., Ghosh P., Elsner R.F., 1981, 246, 231

Davies R.D., Elliott K.H., Meaburn J., 1976, Mem.R.Astron.Soc. 81, 89

Davison P.J.N., 1977, MNRAS 179, 15p

Fujimoto M.Y., 1982, ApJ 257, 767

Gardiner L.T., Sawa T., & Fujimoto M., 1994, MNRAS 266, 567

Gottwald M., White N.E., Stella L., 1986, MNRAS 222, 21

Gruber D.E., Rothschild R.E., 1984, ApJ 283, 546

Hammerschlag-Hensberge G., Kallmann T.R., Howarth I.D., 1984, ApJ 283, 249

Heise J., van Teeseling A., Kahabka P., 1994, A&A 288, L45

Henry P., Schreier E., 1977, ApJ 212, L13

Hertz P., Grindlay J., 1983, ApJ 275, 105

Howarth I.D., 1982, MNRAS 198, 289

Hughes J.P., 1994, ApJ 427, L25

Hutchings J.B., Crampton D., 1977, ApJ 217, 186

Inoue H., Koyama K., Tanaka Y., 1983, in: IAU Symposium 101, Supernova Remnants and Their X-Ray Emission, ed. J. Danziger & P. Gorenstein, Dordrecht: Reidel, p.535

Israel G.L., Stella L., Angelini L., et al., 1995, IAU Circ. No. 6277

Kahabka P., Pietsch W., 1993, ROSAT Survey view of the SMC, in: Lecture Notes in Physics 416, New Aspects of Magellanic Cloud Research, eds. Baschek B., Klare G., Lequeux J., 71

Kahabka P., Pietsch W., Hasinger G., 1994, A&A 288, 538

Kahabka P., 1995a, *ROSAT observations of supersofts and transients in the Magellanic Clouds*, in: *The Lives of Neutron Stars*, ed. H.A. Alpar, Ü. Kiziloglu and J. van Paradijs, NATO ASI series Vol. 450, Kluwer

Kahabka P., 1995b, A&A 304, 227

Kahabka P., 1996, A&A 306, 795

Kahabka P. et al., 1996 (in prep.)

Kahabka P., & Pietsch W., 1996, A&AS (in prep)

Kunz M., Gruber D.E., Kendziorra E., et al., 1993, A&A 268, 116

Levine A., Rappaport S, Deeter J.E., et al., 1993, ApJ 410, 328

Lewin W.H.G., van Paradijs J., & Taam R.E., 1993, Space Sci.Rev. 62, 223

Liller W., 1973, ApJ 184, L37

Livio M., 1994, *Topics in the Theory of Cataclysmic Variables and X-Ray Binaries*, in *Interacting Binaries*, ed. H. Nussbaumer, & A. Orr, Springer, 135

Long K.S., Helfand D.J., Grabelsky D.A., 1981, ApJ 248, 925

Lucke R., Yentis D., Friedman H., et al., 1976, ApJ 206, L25

Luks T., 1994, Rev.Mod.Astr. 7, 171

Maraschi L., Treves A., van den Heuvel E.P.J., 1976, Nat 259, 292

Marshall F.E., White N.E., Becker R.H., 1983, ApJ 266, 814

McGee R.X., and Hindman J.V., 1971, quoted by F.J. Kerr, in *The Magellanic Clouds*, ed. A.B. Muller (Dordrecht: Reidel).

Murdin P., Morton D.C., Thomas R.M., 1979, MNRAS 186, 43^P

Orio M., Della Valle M., Massone G.,et al., 1994, A&A 289, L11

Osmer P.S., Hiltner W.A., 1974, ApJ 188, L5

Pagel B.E.J., 1993, Stellar vs. Interstellar Abundances in the Magellanic Clouds, in: Lecture Notes in Physics 416, New Aspects of Magellanic Cloud Research, eds. Baschek B., Klare G., Lequeux J., 330

Pakull M.W., Beuermann K., van der Klis M., et al., 1988, A&A 203, L27

Papalaizou J., 1979, MNRAS 186, 791

Parmar A.N., White N.E., 1988, in: X-ray astronomy with *EX-OSAT*, ed. NE. White, R. Pallivinci, Memoria S.A.It 59, 147

Pfeffermann E., Briel U.G., Hippmann H., et al., 1986, Proc. SPIE 733, 519

Pietsch W., Collmar W., Gottwald M., et al., 1986, A&A 163, 93

Pollock A.M.T., Bignami G.F., Hermsen W., et al., 1981, A&A 94, 116

Price R.E., Groves D.J., Rodrigues R.M., et al., 1971, ApJ 168, L7

Primini F., Rappaport S., Joss P.C., 1977, ApJ 217, 543

Primini F, et al. 1993, ApJ 410, 615

Pye J.P., McGale P.A., Allan D. J., et al., 1995, MNRAS 274, 1165

Rappaport S., Di Stephano R., Smith J.D., 1994, ApJ 270, L9

Reynolds A.P., Hilditch R.W., Bell S.A., et al., 1993, MNRAS 261, 337

Ross R.R., 1979, ApJ 233, 334

Sanduleak N., Philips A.G., 1977, IAU Circ. No. 3127

Schlosser W., van Paradijs J., 1979, A&A 75, 112

Schmidtke P.C., Cowley A.P., McGrath T.K., et al., 1994, IAU Circ. No. 6107

Schreier E., Giacconi R., Gursky H., et al., 1972, ApJ 178, L71

Seward F.D., Mitchell M., 1981, Ap.J 243, 736

Skinner G.K., Bedford D.K., Elsner R.F., et al., 1982, Nat 297, 568

Stella L., White N.E., Rosner R., 1986, ApJ 308, 669

Tarenghi M., Tanzi E.G., Treves A., et al., 1981, A&AS 43, 353

Trümper J., Hasinger G., Aschenbach B., et al., 1991, Nat 349, 579

Trümper J., 1983, Adv. Space Res. 2,241

Tuohy I., Rapley C.G., 1975, ApJ 198, L69

Tuohy I. R., Buckley D. A. H., Remillard R. A., et al., 1988, in *Physics of Neutron Stars and Black Holes*, ed. Y. Tanaka (Tokyo: Universal Academic Express)

van den Heuvel E.P.J., 1992, in *X-Ray Binaries and Recycled Pulsars*, ed van den Heuvel E.P.J. and Rappaport S.A., 233

van den Heuvel E.P.J., Bhattacharya D., Nomoto K., et al., 1992b, A&A 262, 97

van den Heuvel E.P.J., 1994, *Topics in Close Binary Evolution*, in *Interacting Binaries*, ed. H. Nussbaumer, & A. Orr, Springer, 263

van der Klis M., Hammerschlag-Hensberge G., Bonnet-Bidaud J.M., et al., 1982, A&A 106, 339

van Genderen A.M., 1974, MNRAS 167, 57p

van Genderen A.M., van Groningen E., 1981, A&A 101, 101

van Paradijs J., Zuiderwijk E., 1977, A&A 61, L19

van Paradijs J., 1977, ApJ 223, L79

van Paradijs J., McClintock J.E., 1995, *Optical and Ultraviolet Observations of X-Ray Binaries*, in: X-Ray Binaries, eds. W.H.C. Lewin, J. van Paradijs, & E.P.J. van den Heuvel, Cambridge University Press

van Paradijs J., 1995, *A Catalog of X-Ray Binaries*, in: X-Ray Binaries, eds. W.H.C. Lewin, J. van Paradijs, & E.P.J. van den Heuvel, Cambridge University Press

Verbunt F., van Paradijs J., et al., 1984, MNRAS 210, 899

Vogel M., Morgan D.H., 1994, A&A 288, 842

Voges W., 1992, the ROSAT All-Sky X-Ray Survey. In: Proc. European ISY meeting, Symposium "Space Sciences with particular emphasis on High Energy Astrophysics", p223

Wang Q., 1991, MNRAS 252, 47^p

Wang Q., Wu X., 1992, ApJS 78, 391

Waters L.B.F.M., van Kerkwijk M.H., 1989, A&A 223, 196

Webster B.L., Martin W.L., Feast M.W., et al., 1972, Nat.Phys.Sci. 240, 183

White N.E., 1989, A&AR 1,85

Whitlock L., Lochner J. C., 1994, ApJ 437, 841

Wilson R.E., Wilson A.T., 1976, ApJ 204, 551

Woo J.W., Clark G.W., Blondin J.M., et al., 1995, ApJ 445, 896

Wood K.S., et al., 1984, ApJS 56, 507

Ye T., Turtle A.J., & Kennicutt R.C., 1991, MNRAS 249, 722

Ye T., & Turtle A.J., 1993, *A High Resolution and High Sensitivity Survey of the SMC at 843 MHz*, in: Lecture Notes in Physics 416, New Aspects of Magellanic Cloud Research, eds. Baschek B., Klare G., Lequeux J., 167

Zimmermann H.U., Belloni T., Izzo C., et al., 1993, MPE report 244